INSTITUTE OF PAPER CHEMISTRY
Appleton · Wisconsin

HIGH-INTENSITY DRYING PROCESSES

Project 3470

Report Two

to

MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

February, 1988

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HIGH-INTENSITY DRYING PROCESSES - IMPULSE DRYING REPORT TWO

By
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TABLE OF CONTENTS

SUMMARY

The past two years of Department of Energy supported research on impulse drying have established the process as one of the most promising alternatives to conventional cylinder drying of paper and paperboard. The early work on impulse drying, documented in the first Progress Report in this series (1), identified the potential of the process as part of a study of several novel drying and pressing technologies. The second year's work, which is summarized in Progress Report Two (2) included an extensive study on the response of several commercially important grades to impulse drying. The excellent performance of the process in terms of water removal, energy use and properties development was demonstrated during these studies. The present Progress Report covers work completed between October, 1986 and September, 1987. The principal project activity during that period was the design, construction, and preliminary testing of a pilot-scale roll impulse dryer. In addition to this significant equipment development task, experiments were performed to evaluate the effects of impulse drying on very wet sheets and to further develop mechanistic understanding of the process. The major conclusions from these efforts are

1. Impulse drying continues to perform well when implemented in a pilot-scale roll geometry. Water removal and properties development are similar on the roll press and on the platen press used in earlier experiments. Initial work on the roll press using intense impulse drying conditions has produced 42 pounds per thousand square feet linerboard with strength properties similar to 69 pound board.

2. The energy use and water removal performance of impulse drying improves rapidly as sheet moisture content is increased. Impulse drying

may be able to replace portions of the press section of conventional paper machines, as well as part of the dryer section. Water removal rates can be twice those which would be found in an unheated press operating at the same pressure and nip residence time. The drying system energy consumption, including impulse dryers and conventional dryers to complete the dewatering process, can be less than half the requirement of conventional papermaking if impulse drying is implemented in a third press position.

3. Linerboard sheet surface properties important in the production of combined board are improved by impulse drying. Glueability of board, as measured on The Institute of Paper Chemistry Double-Backer Bonding Simulator equipment, is enhanced after impulse drying.

4. The range of grades to which impulse drying can be applied or the range of conditions which can be used may be limited by delamination phenomena. Wet webs with low internal strength and high resistance to vapor and liquid flows will blister or delaminate if the vapor pressure in the web cannot be relieved before the sheet leaves the impulse dryer press nip. Several approaches to the problem have been identified and will be examined in detail during 1988.

Work is continuing on characterizing sheet surface quality after impulse drying in terms of its effects on conversion to the final product. Corrugating medium, newsprint, writing papers, and lightweight coating rawstock are now being evaluated for their conversion response to impulse drying.

INTRODUCTION

OVERVIEW AND OBJECTIVES

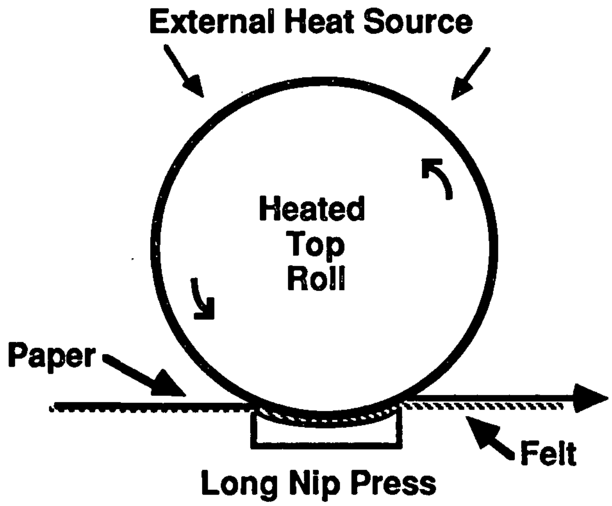
The pulp and paper industry is one of the largest industrial consumers of energy in the United States. Paper industry annual energy use is comparable to that of the primary metals, chemicals, and oil industries. Statistics collected by the American Paper Institute (3) indicate that the total energy use of the industry is approximately 2 .1 Quads (2,100,000,000,000,000 BTUs) annually. Nearly 30 million BTUs are used to make each ton of the annual 70 million tons of paper and board produced by the industry.

Drying paper is the largest single energy demand in papermaking. The typical steam heated cylinder dryer uses between 6.5 and 12.5 million BTUs per ton, or about one-quarter of the total energy demand of the entire pulp and paper process (4). Even modest reductions in the energy demands of paper drying could conserve large amounts of energy.

Significant progress has been made in developing a promising new technology called Impulse Drying. The characteristic features of impulse drying are the use of pressures and temperatures at much higher levels than normally used in paper drying, but with a very short exposure of the sheet to these intense conditions. The process concept in its present form was suggested by Wahren (5). A related high-intensity drying method has been described mechanistically by Williams, Halsey and Gottwald (6). The conditions required to perform impulse drying appear to be attainable by combinations of existing pressing and heat transfer technologies.

A conceptual sketch for a roll impulse dryer is illustrated in Figure 1. Impulse drying works by bringing the wet paper into contact with a very hot metal roll, typically at 400°F to 700°F, while maintaining pressure on the sheet at 400 to 700 pounds per square inch for between 15 and 100 milliseconds. The equipment needed to provide the pressure and time conditions is already available from several manufacturers; impulse drying involves adding a source of heat to these "wide nip presses" to raise the temperature of the process.

Figure 1. The impulse drying concept: wide-nip press technology modified to include a very hot press roll.



Once sufficient temperature, pressure, and time are provided, water is removed from the sheet by a mechanism which is fundamentally different from conventional paper drying. Student research at the IPC (7), (8) has shown that under these conditions high pressure steam is generated rapidly in the surface of the sheet next to the hot roll. Growth of the steam layer displaces liquid water from the sheet into the water receiver, typically a press felt. The rates of water removal achieved by this vapor displacement mechanism are 100 to 1000 times greater than in conventional drying. Large amounts of water are removed from the sheet in the liquid phase, saving the energy which would otherwise be used to evaporate the water from the sheet. This report includes a summary of additional work which has extended this mechanistic understanding to sheets as wet as 35% solids.

Impulse drying also has substantial effects on sheet properties. Sheet temperatures near the hot surface increase to levels which promote fiber conformability and interfiber bonding, particularly if the sheets are formed from high-yield, high lignin content furnishes. Impulse drying is generally stopped before the sheet is completely dry, and the vapor flashing in the sheet interrupts the densification process. The sheet is left with a distinctive density profile; a combination of surface density and midsheet bulk which is advantageous in the development of many important physical properties.

The potential effects of impulse drying on paper industry energy use are very significant. Over eighty percent of the water removed from the sheet can be removed in the liquid phase, with the result that the amount of energy required can be as low as 200 BTU per pound of water removed. Conventional cylinder drying has much higher energy requirements, approaching 1600 to 1800 BTU/lb to evaporate water and transport the vapor away from the machine in many cases.

If impulse drying is widely commercialized, a conservative estimate may be made that current paper industry energy use can be reduced by at least ten percent, for a total savings of about 0.2 quad of energy per year. If the paper strength improvements from impulse drying are used to increase recycled fiber and high-yield pulp use, the savings may substantially exceed this level.

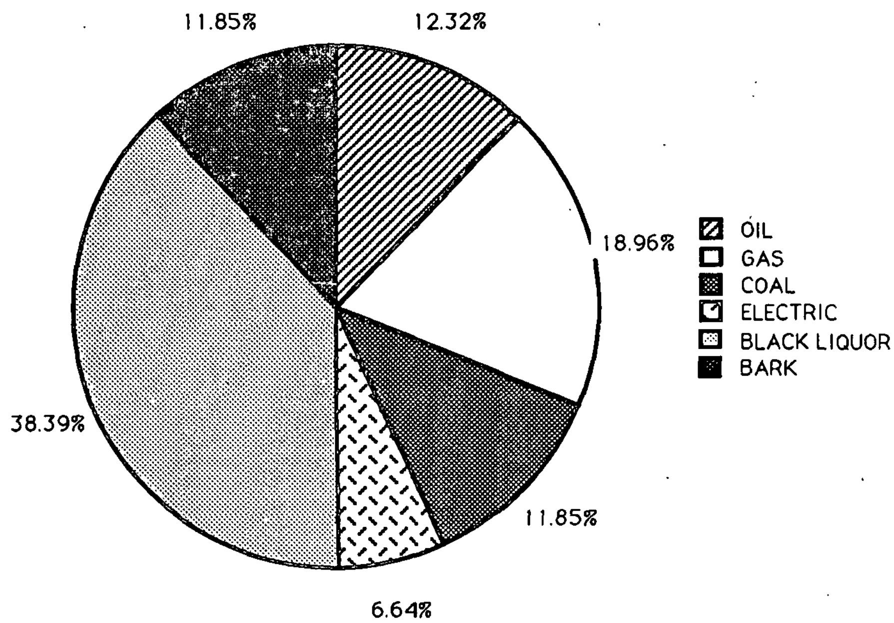
The work performed during the current project year has been of two types. First, a pilot roll impulse dryer was designed, built, and used in a series of preliminary experiments. The purposes of this pilot device include demonstrating that the process works in a realistic roll geometry and providing large paper samples for conversion testing. The second major type of project work has been an extension of previous experiments on water removal and energy use during impulse drying to much wetter sheets than were studied earlier. These tests were performed to determine whether impulse drying can be effective as a substitute for at least part of the conventional wet pressing process, as well as providing an alternative to cylinder drying. In addition, a small amount of work was performed to provide fundamental information on the effects of pressure pulse shape and sheet moisture content on heat release during impulse drying, and to indicate the effects of sheet flow resistance on delamination. This report will present data from all of these project activities.

BACKGROUND

Energy Use in the Pulp and Paper Industry

The pulp and paper industry is the fifth largest manufacturing industry in the United States, and accounts for more than ten percent of the total energy used by domestic manufacturers. In 1984, the pulp and paper industry used about 2.2×10^{15} BTUs (3). At present, about one-half of the total energy is self-generated, principally from the combustion of spent cooking liquors and wood wastes. The balance is generated from natural gas, residual oil, coal and purchased electricity in the ratios shown in Figure 2.

Figure 2. The fuel use distribution of the United States pulp and paper industry (3).



The largest fraction of this energy use, about 40% of the total, is consumed in the papermaking process, of which drying is the largest single demand. An energy balance for a typical bleached paper mill is shown in Figure 3. The typical steam heated cylinder dryer section uses nearly one-third of the total energy requirements of an integrated mill, and an even larger fraction of the energy needs of a nonintegrated mill.

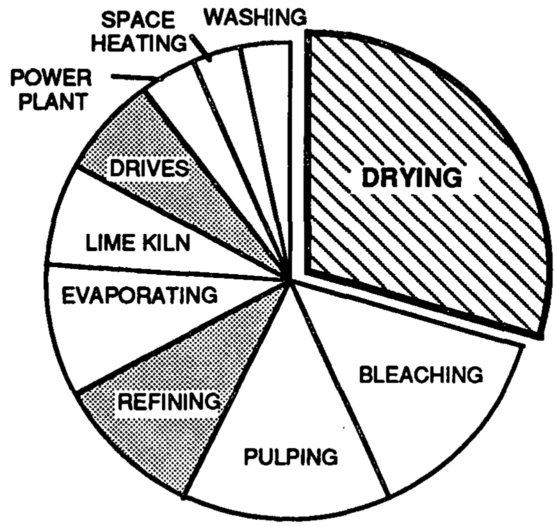


Figure 3. Energy requirements for pulp and papermaking.

Much of this energy consumption in conventional drying is used up in the inefficiencies of the process. In terms of the traditional dryer efficiency expressed as the pounds of steam required to remove each pound of water from the sheet, the minimum theoretical requirement to heat one pound of water from 90°F to 212°F and evaporate it at atmospheric pressure is 1.09 pound steam per pound water. In practice, a "steam economy" of 1.25 to 1.3 would be considered excellent, with values above 1.5 common in older equipment. The extra heat is consumed in a number of ways, including heating the air which carries away the water vapor, heat used to raise the sheet temperature, losses through convection and radiation, and, in the final portion of the drying section, the heat required to remove water which is physically or chemically bound to the fibers.

Impulse drying eliminates a number of these inefficiencies. Since much of the water removed is displaced from the sheet in the liquid phase, far less water has to be evaporated than in conventional cylinder dryers. In addition, only a small amount of water vapor is released from the sheet into the surrounding air, both because less steam is produced initially and because some of the vapor will condense in the water receiver. Thus, the amount of air which will have to be heated to transport the water vapor away from the sheet should be reduced to a very small quantity. Impulse drying equipment will be much smaller physically than conventional dryer sections, which will simplify the task of reducing radiative and other heat losses to the machine room.

Data summarized later in this report show that about one-half of the energy now used to dry paper can be saved by a combination of impulse drying in the third press position to between 60 and 70% solids, followed by conventional dryers to complete the drying process. The potential energy impact of impulse drying is very large, even if the ultimate market penetration of the process is incomplete:

(Energy use of 2.2 Quads per year) x (30% used for drying) = 0.66 Quad used for drying

(0.66 Quad used for drying) x (50% potential savings) = 0.33 Quad potential savings

(0.33 Quad potential) x (60% market penetration) = 0.2 Quad saved.

The potential energy savings from using impulse drying instead of conventional drying thus approach 10 percent of the total energy consumption of the pulp and paper industry. Additional savings from low energy cost high yield fiber substitutions made possible by impulse drying are also likely.

Other Incentives for Impulse Drying

In addition to their low energy efficiency, conventional dryer sections are physically large and therefore capital intensive. The large size of cylinder dryers is a result of the low drying rates (expressed as pounds of water evaporated per hour per square foot of heat transfer surface) typical of the process. For most commercial grades, the drying rate is typically in the range of 2 to 5 pounds per hour per square foot (9), which results in dryer sections with a total heat transfer area as large as one acre. The large size of conventional dryers contributes substantially to the capital costs of both new mills and machine rebuilds.

Impulse drying has water removal rates between 100 and 1000 times those found in conventional sections (2). Impulse drying equipment would be much smaller than conventional dryers. This would be particularly important in rebuilds of existing paper machines, which are often limited in their production capacity by the dryer section. The major and costly modifications to the machinery and building needed to produce a worthwhile production increase, given the large amounts of heat transfer surface needed to evaporate more water, can pose an insurmountable obstacle to investment. Impulse drying could help release this productive capacity, as well as improving the capital cost picture for new mills.

Another significant opportunity for impulse drying comes from the ability of the process to increase the strength of high yield and recycled furnishes. The use of these low energy and low raw material cost materials in papermaking is limited by the relatively poor product properties which are obtained when they are processed conventionally. However, impulse drying has been shown (2) to be able to bring the strength of such furnishes up to the levels expected in the marketplace. The energy, capital, and materials savings will be very large if this aspect of impulse drying can be realized.

Project Objective and Plans

The principal objective of this project is to provide the data necessary to support and encourage commercial implementation of the impulse drying process. Figure 4 presents the project flowchart which has guided research in this area for the past three years. The program began with exploratory and feasibility work, which was completed in 1985 and documented in Progress Report One (1). Work on step two, the investigation of water removal mechanisms, has progressed with the assistance of student theses, notably those of Burton (7) and Devlin (8). A major portion of step three, obtaining technical performance data on a number of commercially important grades, was performed in 1986 and documented in Progress Report Two (2), although work in this area will continue throughout the life of the project. The preliminary engineering concepts of step four which were needed to build the pilot roll impulse dryer were developed during 1986, and have been further refined during this year's construction process.

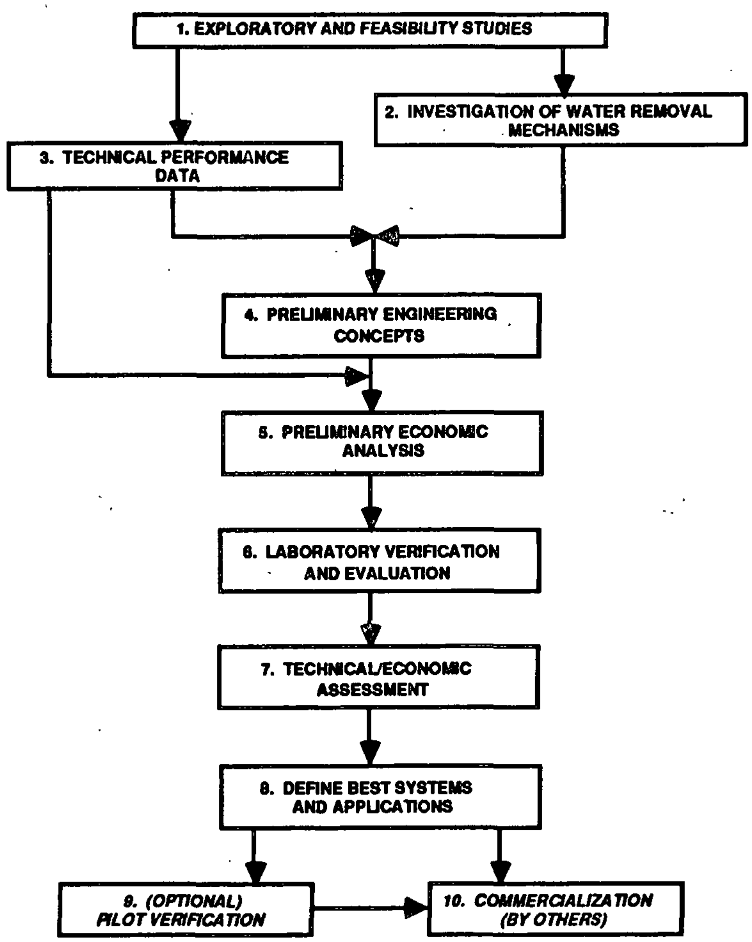


Figure 4. Project plan flowsheet.

Recent work on the project has concentrated on Step 6, the laboratory verification and evaluation of the process using pilot scale equipment, with further work on mechanisms and technical performance data, Steps 2 and 3. Work is continuing on laboratory pilot scale evaluation, and on technical and economic assessment of the process (Steps 5 and 7).

Review of Key Data from Past Work

The new data which will be presented in this report may be better understood in the context of the overall performance of impulse drying as defined in previous work (2). Recent experimentation has concentrated on one grade, kraft linerboard. This choice reflects both the relative ease of working with that grade, its commercial importance, and the probability that the initial implementations of impulse drying will occur on linerboard machines. Wide nip press technology is found principally on linerboard machines, and the conversion of such a press to an impulse dryer is the most straightforward, and so most likely, means of bringing impulse drying to commercialization.

Recent emphasis on linerboard could obscure the excellent effects impulse drying has on a wide variety of important paper and board grades. A review of the most significant results of the earlier multiple grade studies may help keep current results in perspective.

Past impulse drying studies have evaluated grades which comprise the majority of total United States paper and board production. Grades evaluated to date have included linerboard, corrugating medium, newsprint, uncoated freesheet writing paper, and coated paper rawstock. Together, these grades account for two-thirds of total production (Figure 5). All responded well to impulse drying. The composition of these furnishes is presented in Table 1.

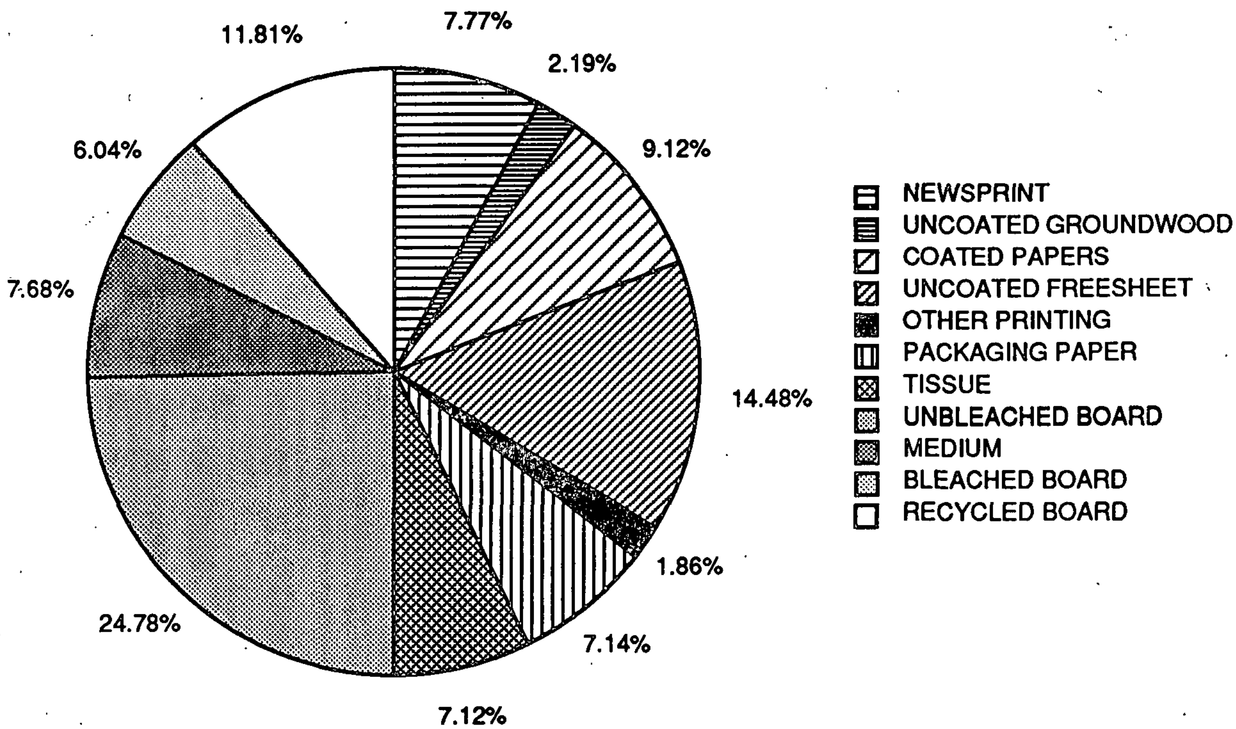


Figure 5. Production figures by grade for the United States paper and board industry between February 1985 and February 1986 (API figures).

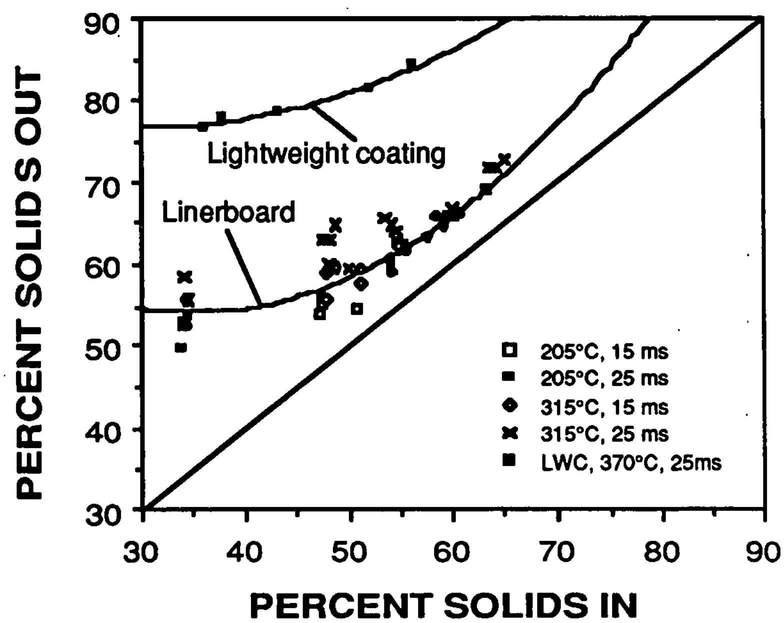
FURNISH	FIBER MAKEUP		
Linerboard	100% UBSWK		
OCC Recycled Liner	100% OCC		
Corrugating Medium	91% NSSC	1.5% UBHWK	7.3% UBSWK
Writing Paper	73% BHWK	27% BSWK	
Newsprint	22% BSWK	78% Groundwood	
Lightweight Coating	47% BSWK	53% TMP	

Table 1. Composition of furnishes used in the technical performance evaluation of impulse drying.

The first major effect of impulse drying is its ability to remove large amounts of water from sheets in very short periods of time. Figure 6 illustrates the sheet final percent solids content achievable with impulse drying. A lightweight grade, such as coating rawstock at 50 grams per square meter, can be dried from 35 to 76% solids in a single, 25 millisecond nip. This performance could potentially eliminate most of the conventional cylinder drying section of a machine producing a similar grade. Heavier weight materials, such as 125 grams per square meter linerboard, are also effectively dewatered by impulse drying, although the final percent solids after a single nip is not as high.

For both grades, the final solids content of the sheet is nearly constant for a wide range of solids entering the impulse dryer. For a lightweight grade, initial solids levels between 35 and 58% can be increased to approximately 78% solids in a single nip. This effect may reduce moisture variability across the machine, making the common practice of overdrying the sheet to achieve a target average reel moisture content unnecessary.

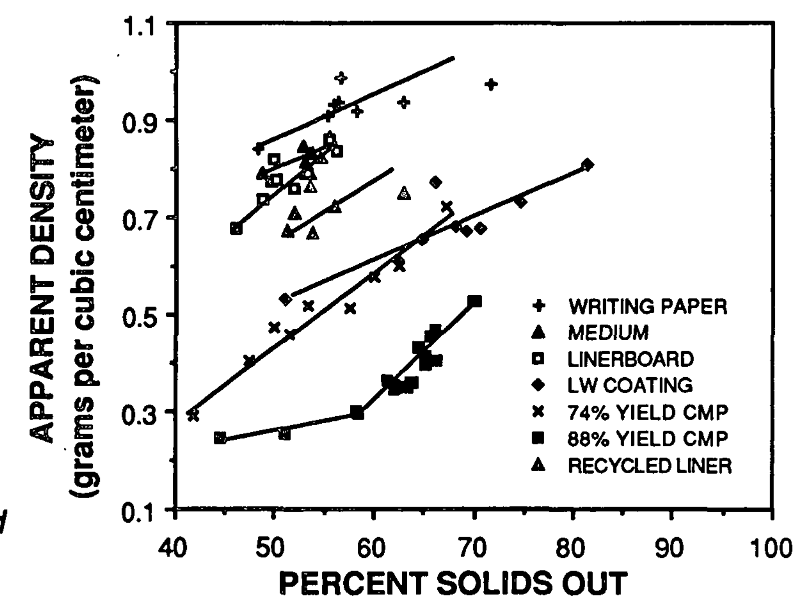
Figure 6. Linerboard and LWC final solids plotted against initial solids content. Linerboard at 125 grams per square meter and LWC at 50 grams per square meter, both preheated to 180°F. Linerboard data include a range of pressures from 400 to 700 psi. Pressure did not significantly impact water removal rates for this grade.



Higher impulse drying temperatures and longer nip residence times favor the production of dryer sheets, but the pressure applied in the nip is of minor importance above about 300 psi peak. Operating at 700°F rather than 400°F increases the final percent solids of the sheet by five percentage points at 35% solids for linerboard. However, the process will be much simpler to implement at lower temperatures due to materials and safety considerations. Preheating the sheet from room temperature to 180°F improves water removal rates by 30 to 50 percent, with most of the additional water removal occurring in the liquid phase (2).

A further major effect of impulse drying is a significant increase in sheet density. The combination of temperature, pressure and nip residence time produce conditions which promote fiber conformability and bond development (7). In general, the apparent density produced by impulse drying is a straight-line function of the percent solids after impulse drying. (Figure 7). The temperature, pressure, and time used to attain the final percent solids do not influence the final density appreciably. For all the grades

Figure 7. IPC apparent density development for several commercially important grades. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter, newsprint and lightweight coating rawstock at 50 grams per square meter and writing paper at 80 grams per square meter. Data include peak pressures at 400 and 700 psi, temperatures from 400 to 700°F, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 70°F.

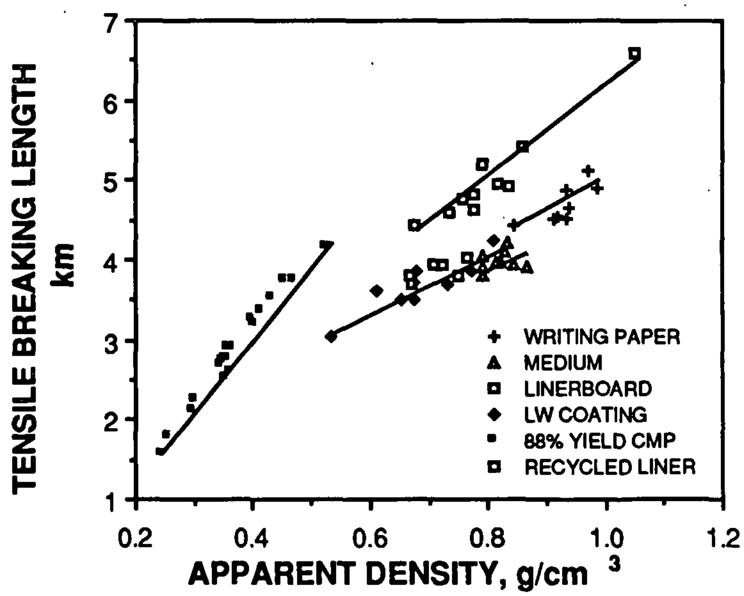


shown in Figure 7, the point furthest to the left represents a conventionally processed sheet which has received no impulse drying; the remaining points were obtained by impulse drying at a variety of conditions.

Impulse drying increased the density of all grades tested. However, the density increases were particularly large for high-yield chemimechanical pulp. Such high-yield grades are difficult to consolidate using conventional technology, and so tend to produce weak sheets. The highest yield material, at 88% yield, densified slowly under mild impulse drying conditions, but resumed a linear relationship between density and final solids above 55% final solids. The density of both high-yield pulps was more than doubled at the most intense impulse drying conditions tested.

The density increases presented in Figure 7 correspond to improved bonding between fibers in the sheet, leading to improved physical properties. Strength properties tend to be straight-line functions of the apparent density, with little dependence on the temperature, pressure, or nip residence time used to produce the densification. For example, the tensile strength of all grades was improved by impulse drying (Figure 8).

Figure 8. Tensile strength development with densification for several commercially important grades. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter, newsprint and lightweight coating rawstock at 50 grams per square meter and writing paper at 80 grams per square meter. Data include peak pressures at 400 and 700 psi, temperatures from 400 to 700°F, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 70°F.

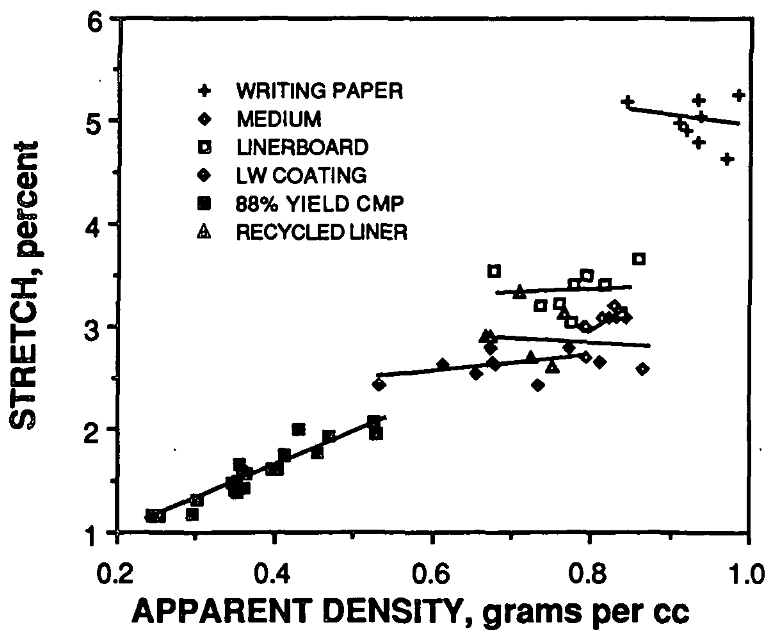


The tensile strength of high-yield chemimechanical pulp sheets is very low after conventional processing, about 2 kilometers of breaking length. Impulse drying can bring the tensile strength of this material to the 4.3 kilometer level characteristic of conventional 50% yield kraft pulp at the same 125 grams per square meter basis weight.

The remarkable improvements in the strength of high-yield furnishes is consistent with recent student research at The Institute of Paper Chemistry. Dundore (10) observed increases in both relative bonded area and specific bond strength with even small amounts of impulse drying for the 88% yield chemimechanical pulp furnish. Softening and flow of the lignin and hemicellulose components of this pulp are believed responsible for these results. The extent of strength development is striking, given the short exposure times to high temperatures provided by impulse drying.

The amount that sheets can be stretched before failure occurs also increases with higher density from impulse drying (Figure 9), although the increases are small for certain grades. Embrittlement of the sheet due to excessively high sheet temperatures

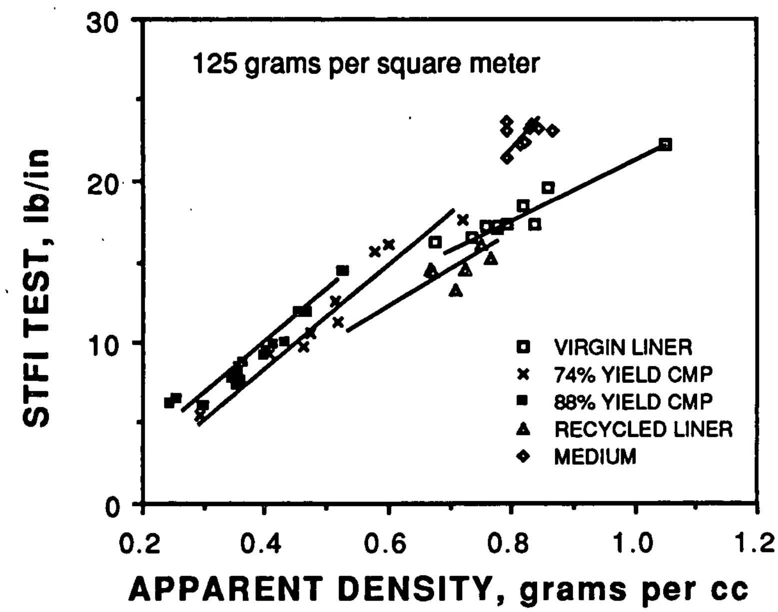
Figure 9. Percent sheet stretch at failure for several commercially important grades. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter, newsprint and lightweight coating rawstock at 50 grams per square meter and writing paper at 80 grams per square meter. Data include peak pressures at 400 and 700 psi, temperatures from 400 to 700°F, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 70°F.



would be expected to reduce stretch. This embrittlement is not observed for the grades and conditions tested. Improvements in stretch are particularly important in the case of corrugating medium, where the ability of the sheet to stretch during the flute forming process is a major factor in runnability on the corrugating machinery.

Compressive strength properties are also enhanced by impulse drying. Figure 10 summarizes the STFI compression test performance of linerboard, medium and alternative linerboard furnishes. Conventionally processed chemimechanical pulp furnishes have one-third the compressive strength of typical kraft linerboard. After impulse drying, the STFI performance of these grades can actually exceed that of kraft pulp at a constant density. This suggests that the bond strength of the high-yield materials is higher than the kraft sheet, possibly due to softening and flow of the lignin content of the chemimechanical pulp.

Figure 10. STFI compression test for medium and several alternative linerboard furnishes. Medium, linerboard, recycled liner and CMP grades all at 125 grams per square meter. Data include peak pressures at 400 and 700 psi, temperatures from 400 to 700°F, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 70°F.



Under many impulse drying conditions, the density profile produced in the sheet will be nonuniform. The region in the sheet near the hot surface tends to densify under the influence of local high temperatures which promote softening and conformability of the fiber constituents. The middle of the sheet is not exposed to high temperatures during most impulse drying conditions and so densifies differently. In addition, the middle of the sheet tends to expand at the end of the nip as hot water flashes to vapor. Additional data to define these phenomena were obtained during the past year and will be summarized later in this report.

Photomicrographic evidence for a nonuniform density profile is shown in Figure 11, taken from Burton's thesis (7). Room temperature wet pressing produces a density profile through the sheet which indicates that the apparent density is the consequence of a random variation of local density at various points through the sheet thickness. Increasing the hot surface temperature to 700°F and impulse drying under the same pressure and nip residence time conditions produces a notable increase in density in the 25% of the sheet thickness closest to the hot surface. The middle of the sheet is relatively bulky, with many open fiber lumens and an overall appearance which is not significantly different from the results of wet pressing.

This nonuniform density profile causes some sheet properties to behave differently than they would if the entire sheet were uniformly densified to an equivalent average density. This presents an opportunity to develop paper and board products with unusual combinations of properties. For example, lightweight coating rawstock (Figure 12) experiences only a four percentage point loss in opacity when its density is increased by 1.5 times. The optical properties of the sheet are retained because most of the light scattering surfaces inside the sheet are only mildly affected by impulse drying.

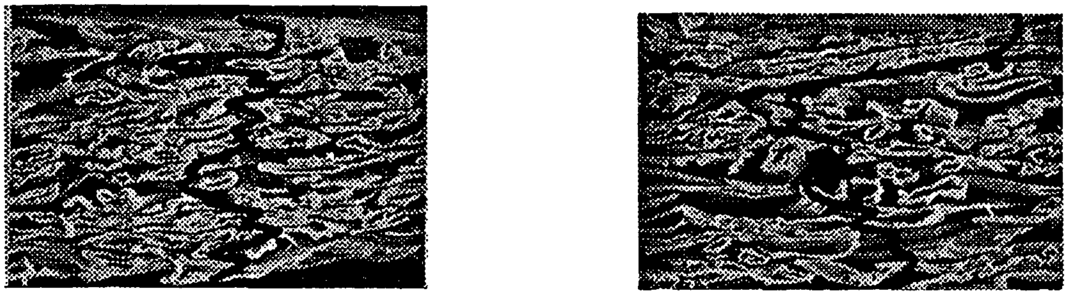
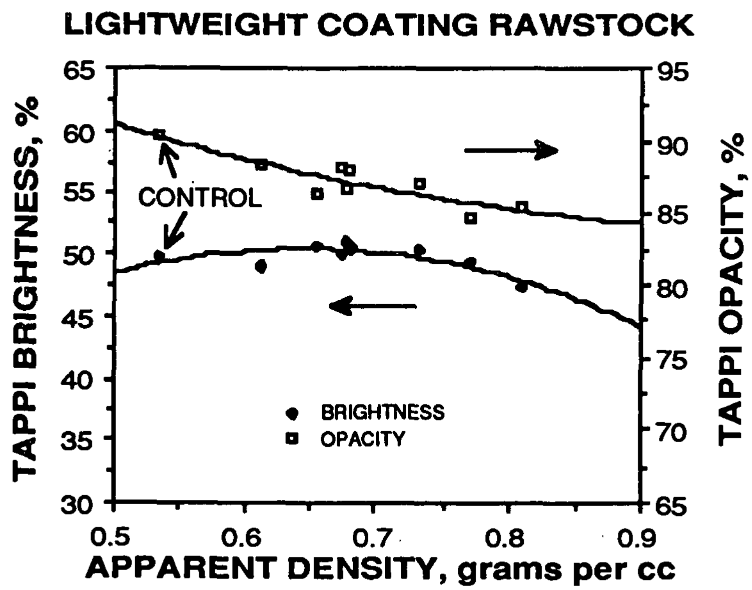


Figure 11. Scanning electron microscope cross sections with density profile mapping of a sheet wet pressed at 68°F and an impulse dried sheet (600°F surface temperature). Both tests were performed on a bleached softwood sheet, 100 grams per square meter basis weight, 735 CSF freeness, with a peak pressure 780 pounds per square inch and nip residence time of 4.5 milliseconds.

Figure 12. TAPPI brightness and opacity for a 50 grams per square meter coating rawstock sheet. Data include peak pressures at 400 and 700 psi, temperatures from 400 to 700°F, and nip residence times between 15 and 30 milliseconds. All sheets initially at 50% solids and 70°F.



Finally, the amount of energy required to produce these dewatering and densification effects is small, due to the displacement of liquid phase water from the sheet. Further evidence for this displacement mechanism and its effects on energy use has been obtained over the past year, and will be reviewed later in this report. The initial data on specific energy use in BTUs per pound of water removed from the sheet are shown in Figure 13 for linerboard and in Figure 14 for newsprint. Impulse drying either of these grades requires less than one-half the 1600 to 1800 BTUs per pound typical of cylinder drying. The specific energy requirement for both grades decreases rapidly as initial sheet solids content decreases. This observation indicated a need to extend the energy use database to much wetter sheets, to evaluate whether impulse drying could be effectively implemented as a substitute for part of the conventional wet pressing section, in addition to replacing portions of the cylinder dryers. This effort became a major portion of the recent year's work.

Figure 13. Specific energy use for linerboard. Specific energy as BTUs per pound of total water removed during impulse drying, as calculated using the lithium chloride tracer method. All data at 127 grams per square meter, with sheets preheated to 180°F before impulse drying. Data include a pressure range of 400 to 700 psi peak pressure and 400 to 600°F, at 15 and 25 milliseconds. Data for sheets drier than 58% solids were taken on the reverse side of a previously impulse dried sheet.

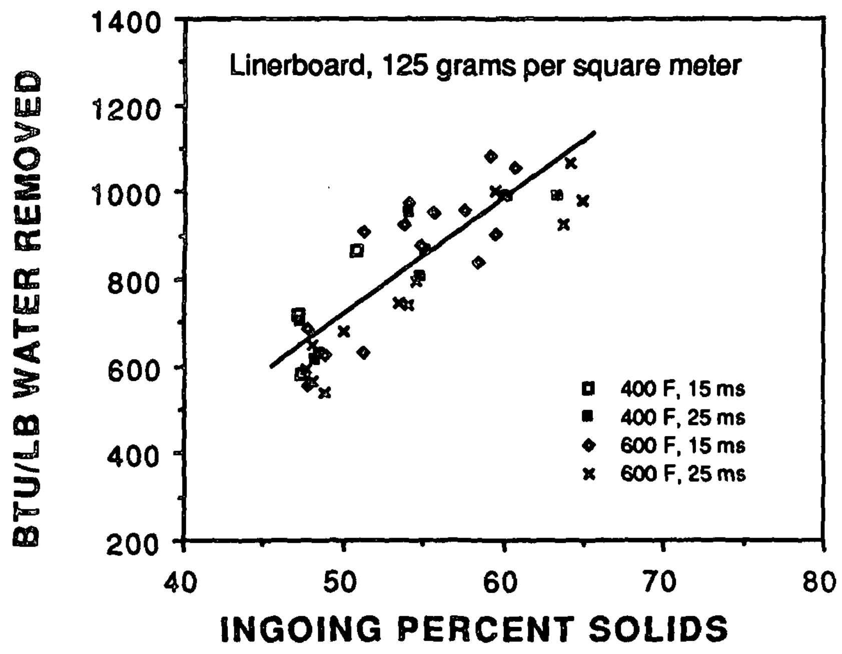
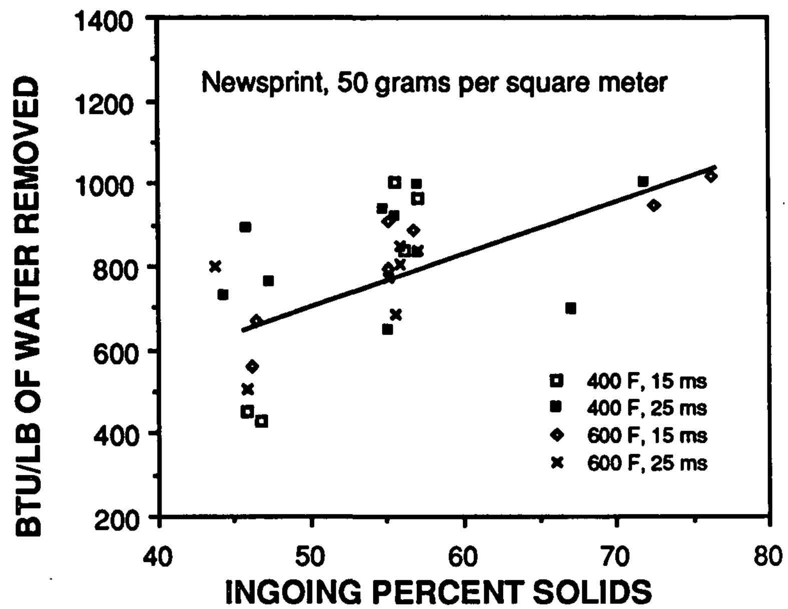


Figure 14. Specific energy use for newsprint. Specific energy as BTUs per pound of total water removed during impulse drying, as calculated using the lithium chloride tracer method. All data at 50 grams per square meter, with sheets preheated to 180°F before impulse drying. Data include a pressure range of 400 to 700 psi peak pressure and 400 to 600°F, at 15 and 25 milliseconds. Data for sheets drier than 58% solids were taken on the reverse side of a previously impulse dried sheet.



PROGRESS IN IMPULSE DRYING RESEARCH

Significant progress was made over the past year in developing further evidence for the mechanisms governing impulse drying, performing pilot-scale verification of the process, and producing large samples suitable for small scale conversion testing. This section will review each of these areas in turn.

MECHANISTIC STUDIES

The mechanisms of impulse drying have been studied extensively at The Institute of Paper Chemistry over the past three years. Most of this work was done in the course of student theses (7) (8), and involved relatively dry sheets. This work was continued during 1987 to develop mechanistic data from wetter sheets than previously studied to evaluate impulse drying as a substitute for wet pressing. One commercially significant furnish, never-dried kraft linerboard at 125 grams per square meter basis weight, was selected for use in these experiments. The response of this furnish has been otherwise well characterized, as summarized in the previous Progress Report for this project (2).

Experimental methods

A variety of experimental techniques was used in this study to simulate impulse drying on the bench scale and to measure heat transfer, water removal, and web compression. All work was done on handsheets using the bench-scale impulse drying simulator illustrated in Figure 15. This device consists of a heated platen and a Materials Testing Systems (MTS) electrohydraulic system to provide the pressure pulse which simulates pressure and time conditions in a press nip. This bench-scale press can simulate any likely impulse drying condition, as its actuator capacity is 22,000 lb-force maximum with simple adjustment of nip residence times from ten milliseconds on up. The electronic control system allows a wide range of pressure-time profiles to be produced reproducibly. A load cell above the upper platen is used to measure and control the total load and the pressure profile.

The platens are five inches in diameter, which allows paper samples to be tested which are large enough for most standard physical test methods. A presteaming ring surrounding the lower platen can be used to raise sheet temperatures to near 180°F before impulse drying.

The total amount of water removed from a sheet and its final percent solids is measured gravimetrically, using the weight of the sheet before and after impulse drying

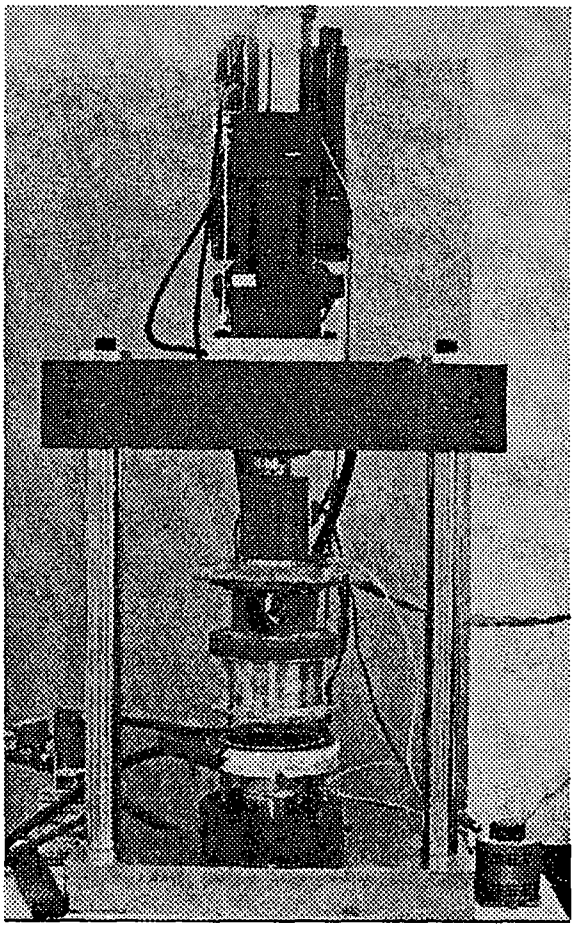


Figure 15. The Institute of Paper Chemistry bench-scale impulse hydraulic press. The ring surrounding the lower platen is used for presteaming sheets to increase their temperature before impulse drying.

and its oven dried weight. Measurement of the separate amounts of liquid phase and vapor phase water removed from the sheet and the energy consumed in the process is more complex.

The principal method used for measuring liquid phase water removal is the lithium chloride tracer technique, which was developed in its present form in C. Devlin's Ph.D. thesis (8). The flowsheet for the method is presented in Figure 16. The pulp slurry is first treated with aluminum nitrate and its pH adjusted to 4.1 with nitric acid, if necessary. The purpose of this step is to saturate the negatively charged sites on the fibers with aluminum ions. After allowing 12 hours for this reaction to occur at all possible sites, a lithium chloride solution is added to the slurry. Handsheets are then formed, using dilution water made up to the same concentration of aluminum nitrate and lithium chloride as in the slurry. The handsheets are prepressed to the desired initial percent solids and impulse dried using the equipment which was described above. After impulse drying, the felt is removed and extracted in one liter of boiling water for twelve hours. The weak salt extract is then analyzed for its lithium content using flame emission analysis. Any lithium in the felt was carried there by liquid water only. The amount of water needed to transport the lithium into the felt is readily calculated from

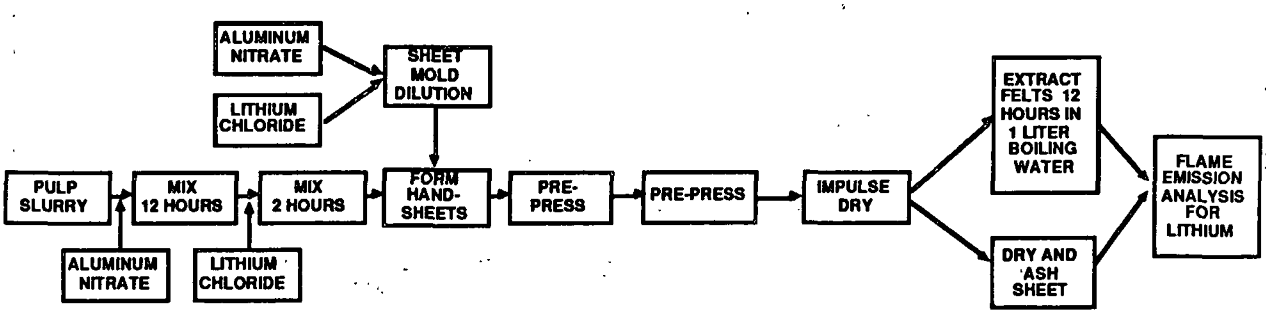


Figure 16. The salt tracer method of measuring liquid water from impulse dried sheets (7).

the initial lithium concentration in the handsheet liquid phase. It is also possible to analyze the sheet for its remaining lithium content, but the process of ashing the sheet and redissolving the ash make this approach much less reproducible.

Once the amount of liquid water removed is known, the amount of water vapor formed can be calculated from the difference between the total water removal, measured gravimetrically, and the liquid phase water removal. The heat required to bring the sheet to its final state may then be calculated from a simple energy balance shown in Table 2. The energy balance requires assumptions about the average pressure at

$$e_{min} = \frac{E_{min}}{(RMR)\, m_{wo}} = \left[\frac{c_f}{m_{ro}} + \frac{c_w}{RMR}\right]\left[T_b - T_o\right] + \left[1 - \alpha_L\right]\Delta h_b + \frac{c_f\left[T_h - T_b\right]}{2\, m_{ro}}$$

c_f	=	specific heat of fiber, BTU/lb/°F
c_w	=	specific heat of water, BTU/lb/°F
e_{min}	=	specific energy use, BTU/lb of water removed
E_{min}	=	heat transferred per pound of fiber, BTU/lb fiber
Δh_b	=	latent heat of vaporization, BTU/lb
RMR	=	Relative moisture removal (dimensionless)
T_b	=	boiling temperature, °F
T_h	=	final hot sheet temperature, °F
T_0	=	initial sheet temperature, °F
α_L	=	fraction of water removed as liquid
m_{wo}	=	initial moisture ratio (lb water / lb fiber)
m_{ro}	=	lbs water removed per lb fiber = m_{wo} * RMR

Table 2. Equation for calculating energy use from liquid water removal data.

which the water vapor forms and about the average temperature to which the water and fiber in the sheet are heated during impulse drying. The balances in this report have been constructed assuming all evaporation occurs at one atmosphere pressure and that all water in the sheet is heated to 212°F. Both of these assumptions are conservative, as the heat of vaporization of water decreases with increasing pressure over the range of conditions of interest in impulse drying, and internal sheet temperature measurements, which will be discussed below, indicate that much of the sheet remains below 212°F.

The probable errors in the lithium chloride technique include adsorption of the lithium by the sheet and felt fibers, lithium losses in handling the samples, and transport of lithium to the evaporation front by the capillary movement of water in the sheet. All of these processes, if they actually occur, will reduce the amount of lithium in the final analysis. If the concentration of lithium in the sheet is reduced by these processes, the material and energy balance calculations will underestimate the amount of liquid water removed and overestimate the amount of energy required to produce the steam. The technique is, therefore, conservative.

The lithium chloride displacement technique measures only the total amount of liquid water removed and the total quantity of energy needed to account for the final state of the sheet. To obtain more detailed information on when heat is released from the hot surface into the sheet during impulse drying, a surface junction thermocouple technique is used. The instantaneous heat flux measurement technique was originally developed for ballistics applications (11). A surface junction thermocouple is made up of concentric cylinders of standard thermocouple metals separated by a fine layer of high temperature insulation. The junction between the metals is made by a layer of plating which bridges the insulation, forming the junction. The active area of the probe is very small, about 0.0005 inch in width and thickness, and so has microsecond response to changes in temperature.

To measure heat flux during impulse drying, the thermocouple tip is mounted flush with the hot surface as shown in Figure 17. During the impulse drying event, changes in temperature with time are measured by the thermocouple and recorded using TransEra high speed data acquisition equipment. The heat flux from the metal surface required to produce the observed temperature history is then deduced from the temperature measurements by assuming that the metal mass acts as a semi-infinite slab initially at constant temperature. The numerical integration which is required is performed using a FORTRAN computer program on a Burroughs B6900 mainframe.

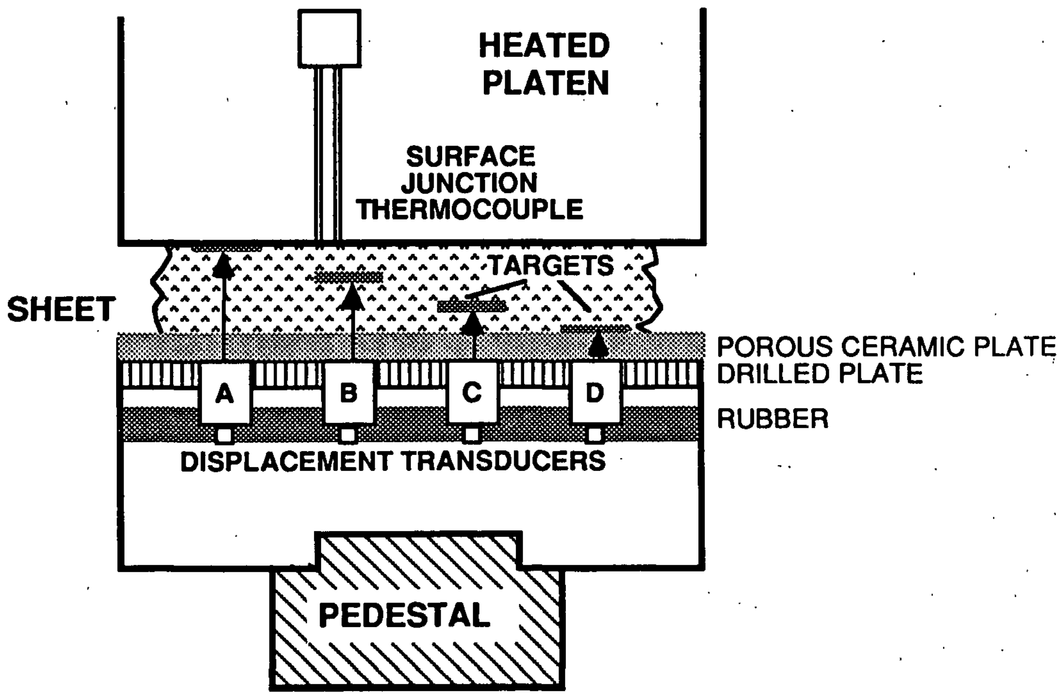


Figure 17. General arrangement of the apparatus for measuring sheet internal caliper changes and surface heat fluxes, as built by Burton (7).

The instantaneous heat flux may be integrated over time to give a measurement of the total heat flux to the sheet. However, the lithium chloride technique is preferred because the known errors are all conservative and so will not overstate the energy effectiveness of the process. The surface junction thermocouple technique is influenced by nonuniformities in the temperature of the heated platen. Extreme care is required in insulating the hot surface before each test to establish a near uniform temperature profile.

The natural tendency of the system to lose heat from the exposed surface leads to temperature gradients in the hot metal plate. Excessive temperature gradients appear in the calculated heat flux history as false negative readings at the end of the nip. These negative heat fluxes occur because heat flows in the hot platen are induced by the original non-uniform temperature profile. The numerical method interprets these heat flows as proceeding from the sheet into the platen surface rather than from the depth of the platen to its surface, which is what is actually occurring. These problems can be minimized by careful experimental technique, but the precautions are time consuming and much data must be rejected because of obvious false negative readings. The small size of the thermocouple junction also introduces the possibility of measuring local heat transfer phenomena, which may not reflect the experience of the sheet as a whole. However, the technique provides valuable data on how heat is released into the sheet if carefully implemented and cautiously interpreted.

Heat flows within the sheet itself have not been measured directly, but can be interpreted from measurements of sheet internal temperature histories. Sheet internal temperature is measured by placing fine-gage thermocouples (0.025 mm diameter) between the layers of handsheets built up of multiple plies. The thermocouples are spaced one-eighth, one-third, two-thirds, and seven-eighths of the way through the sheet thickness. The composite sheet is then pressed to the target moisture content and impulse dried. The signals from the thermocouples were recorded by a high-speed TransEra data acquisition system.

The final measurement used in recent mechanistic studies is the change in sheet thickness during impulse drying. Information on the internal deformations of the sheet has been useful in considering where displacement phenomena may be occurring during the impulse drying event. The dynamic change of sheet thickness in response to applied pressure was measured using a method developed in its present form by Burton (7). Eddy current displacement transducers mounted in the bottom pedestal of the bench impulse drying simulator (Figure 17) were used to follow the motion of small copper mesh targets embedded in handsheets. The targets were dynamically formed into the handsheets, using a special sheet mold originally described by Cowan (12).

The small dimensions (0.0254 mm in thickness) and 65% open area of the copper mesh help secure good integration of the targets into the sheet structure. Targets were positioned at the top and bottom surfaces of the sheet, and inside the sheet at levels corresponding to one-quarter and three-quarters of the total sheet basis weight. The general arrangement of the targets and transducers is shown in Figure 17. The apparent void fraction of the region of the sheet between any two targets can be calculated from the caliper information as follows:

Void fraction=(Total caliper-fiber caliper)/(Total caliper)

Fiber caliper=(Basis weight/density)/(Fraction of sheet thickness between targets).

A fiber solids density of 1.5 grams per cubic centimeter was assumed in the void fraction calculation. An initially uniform distribution of fiber through the sheet was also assumed in these calculations.

Results of Recent Mechanistic Work

The very low energy requirements of impulse drying wet sheets suggested by the data in Figures 13 and 14 indicate an opportunity to implement impulse drying in what is conventionally a wet pressing position. Recent mechanistic work has concentrated on extending the project database to include much wetter sheets than studied previously. A virgin kraft, never-dried unbleached softwood pulp obtained from a southern U.S. linerboard mill was used in these experiments. The pulp was lightly refined to 730 mL CSF, and formed to a 125 grams per square meter basis weight. Five-inch diameter handsheets were formed, couched and stored in sealed plastic bags until needed. Non-standard handsheets containing salt tracer or copper mesh targets or thermocouples were made following the methods outlined in the previous section. The target moisture content before impulse drying was reached by pressing the sheets in a laboratory roll press using press impulse levels typical of commercial equipment. Most of the experiments which will be described below were performed on 35% solids sheets.

Impulse drying represents the addition of a new variable, hot roll surface temperature, to the familiar papermaking process of wet pressing in a wide-nip press. Wet pressing acts to remove water principally through a volume reduction mechanism (13). Water flows from the sheet into a water receiving felt in response to a hydraulic pressure gradient which develops as the sheet is compressed. Although the process of compressing a web to drive out water appears simple, DeCrosta (14) has compiled a list of almost forty process variables which have been found to be significant in the commercial application of wet pressing. Wide nip press technology was developed to enhance the range of one of the principal variables, press impulse, by extending the time available for water to flow from the sheet.

Water removal in a press nip is strongly influenced by the temperature in the web. Raising the web temperature will improve wet pressing performance both by reducing the viscosity of water and by softening the fibers to promote web compressibility. Similar effects are observed as the roll surface temperature is increased toward 212°F. Figure 18 illustrates the effect of increasing the hot surface temperature on the final percent solids achieved in a 25 millisecond nip at 680 psi peak pressure starting from a sheet solids content of 35%. As hot surface temperatures approach 212°F, the final percent solids achieved will climb gradually into the 38 to 42% solids range.

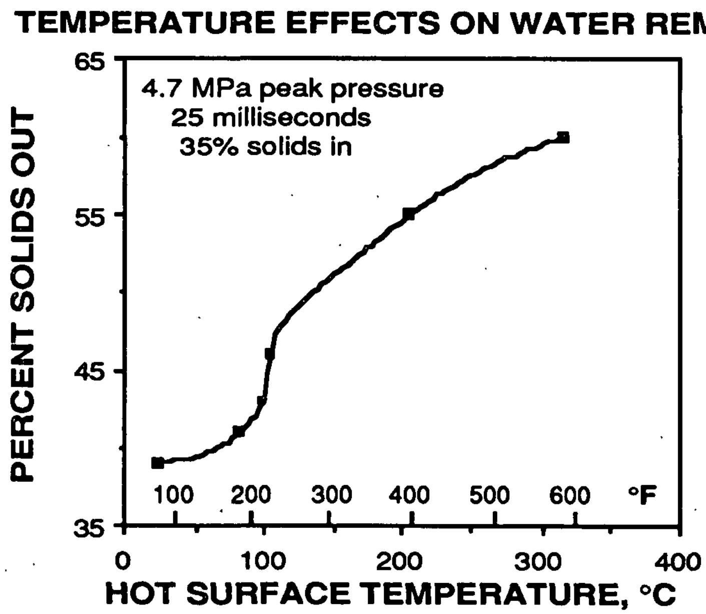
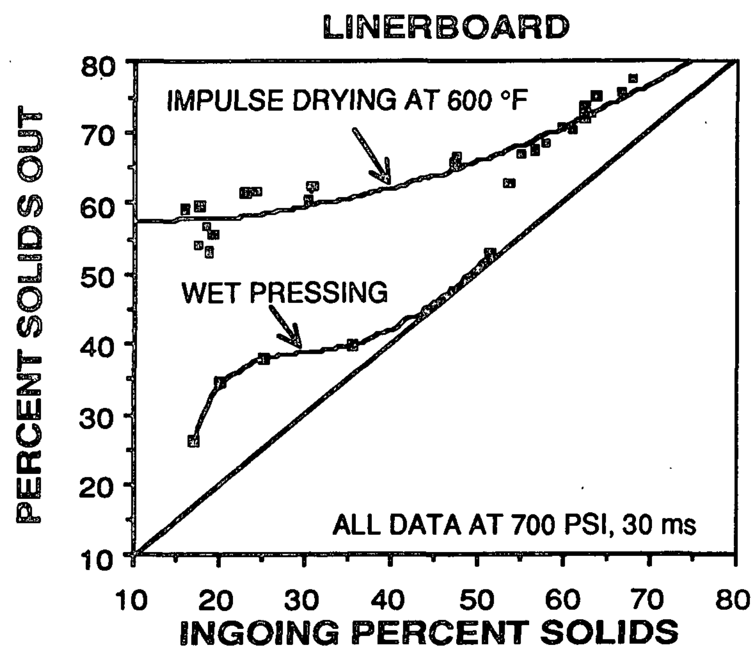


Figure 18. Effects of hot roll surface temperature on the final sheet percent solids of 125 grams per square meter linerboard impulse dried at 680 psi and 30 milliseconds.

Above 212°F, the percent solids out of the nip increases rapidly with further increases in hot surface temperature. At 600°F, impulse dried linerboard sheets can reach 60% solids. However, a portion of this temperature range is not practically useful, as sheet adhesion to the hot surface is a problem between 220° and 380°F. Impulse drying has only been studied in the surface temperature range above 400°F, where sticking is no longer a severe problem.

Increasing the hot surface temperature into the impulse drying regime does more than simply enhance the action of wet pressing. The water removal performance of impulse drying and wet pressing differ in several important respects, as shown in Figure 19. Impulse drying is much less dependent on sheet moisture content than wet pressing. Figure 19 presents a comparison between the sheet dryness after the nip achieved by wet pressing at 80°F with a peak pressure of 700 psi for 30 milliseconds with the results of impulse drying under the same nip conditions but at a hot surface temperature of 600°F. A haversine pressure pulse shape was used in both experiments.

Figure 19. Water removal performance of impulse drying very wet sheets. Wet pressing at 700 psi peak pressure for 30 milliseconds, compared with impulse drying with the same pressure and time conditions at a hot surface temperature of 600°F. Data for linerboard sheets at 125 grams per square meter basis weight preheated to 180°F. Data for sheets drier than 58% solids were taken on the reverse side of a previously impulse dried sheet.



Wet pressing water removal was much less effective than impulse drying under these conditions, and was also much more dependent on sheet moisture content. Impulse drying water removal is only slightly dependent on sheet ingoing percent solids over the range from 15 to 50% solids. The final percent solids level was approximately 58% solids over that range of conditions. In addition the water removal ability of wet pressing was exhausted by about 45% solids, while impulse drying was able to continue to remove water from sheets as dry as 75% solids.

The differences in the behavior of wet pressing and impulse drying shown in Figures 18 and 19 suggest that some mechanism is at work in impulse drying beyond the usual web volume reduction process of wet pressing. The likely mechanism is the displacement of liquid water by steam formed near the interface between the sheet and the hot metal surface. The amount of steam produced during impulse drying can be estimated using the lithium chloride tracer technique outlined above. The tracer technique measures the amount of liquid water received by the felt, while the total amount of water removed from the sheet is measured gravimetrically. The amount of steam formed is calculated from the difference between the total water removed and the liquid phase water removal.

The results of experiments run over a range of initial sheet percent solids between 15 and 65% on 125 grams per square meter linerboard sheets are presented in Figure 20. The results indicate that about 0.25 lb of steam per pound of fiber is produced at all sheet moisture contents between 25 and 65% solids. The steam necessary for a vapor displacement mechanism is thus present at some point during the impulse drying event.

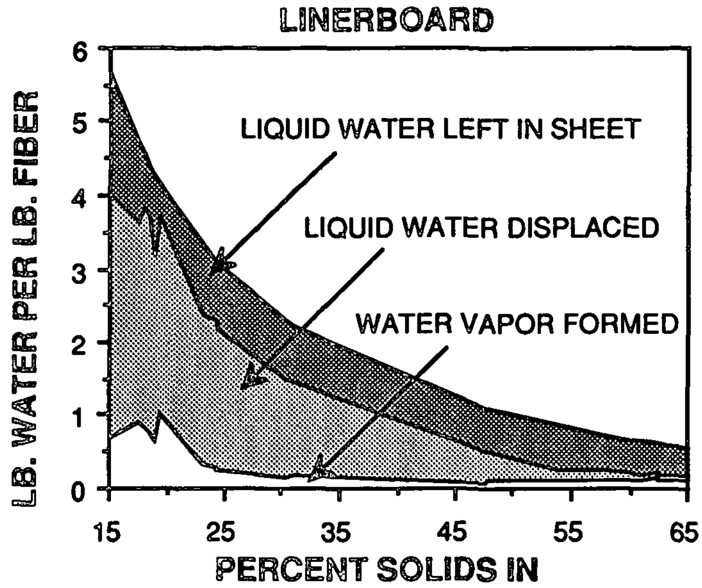


Figure 20. Sheet water balance over a range of initial sheet moisture contents. Data for linerboard sheets at 125 grams per square meter basis weight preheated to 180°F. Impulse drying performed at 700 psi peak pressure at 600°F surface temperature for 30 milliseconds nip residence time.

The amount of liquid water displaced by this steam is a strong function of sheet moisture content. At 65% solids, about thirty percent of the mass of water removed is removed in the liquid phase, but at 25% solids over eighty percent of the water is removed as liquid. This response would be expected in a displacement mechanism. Displacement can only be effective as long as there are few paths for vapor to escape from the sheet without displacing water. Drier sheets increase the possibility of local water-depleted regions through which water vapor could escape into the water receiver without also removing water.

The amount of water left behind in the sheet is also approximately constant over the range of ingoing percent solids tested. About 0.6 lb water per lb fiber remains in the sheet. This quantity of water may represent the level at which significant numbers of paths for vapor to flow past the remaining water in the sheet and escape into the felt begin to appear.

However, even relatively dry sheets exhibit excellent water removal performance when compared with conventional papermaking processes. At 42% solids, the water removal indicated in Figure 20 corresponds to a rate of 2500 pounds of water removed per hour per square foot. This is 500 times the rate which conventional cylinder dryers would produce under typical conditions. Eighty-five percent of that water is displaced rather than evaporated, leading to savings in energy relative to conventional drying. These high water removal rates with substantial liquid phase water removal again point toward a vapor displacement mechanism.

Sheets below 25% solids show an increase in steam production, as may be seen in Figure 20. This effect may be due to an increase in water availability at the sheet surface. Sheets impulse dried above 25% solids may reach a limit in the water supply near the surface before other process limits take effect.

The vapor production data reviewed above do not provide information on when the steam is formed during the nip. Measurement of the instantaneous heat flux from the hot metal surface into the sheet shows that the peak heat flux occurs early in the nip, well before peak pressure is attained (Figure 21). The peak heat fluxes observed are in the 4 MegaWatt per square meter (1.2 million BTUs per hour per square foot) range, which are of the same magnitude as those reported for pool boiling heat transfer (15). It thus seems probable that the peak heat flux occurs in conjunction with the production of steam and so with the major portion of the liquid displacement event. The decline in heat flux, which generally begins before the peak pressure is reached, probably reflects a limitation in the amount of water available near the surface. Additional heat flux phenomena typical of impulse drying will be discussed in the next section.

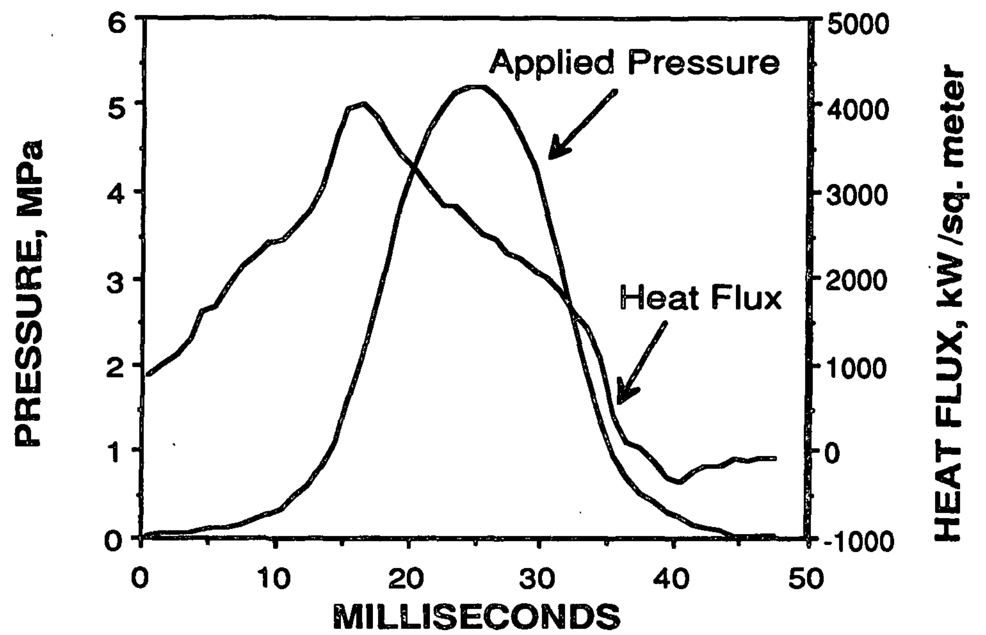


Figure 21. Instantaneous heat flux observed during impulse drying of a 125 grams per square meter kraft linerboard sheet initially at 35% solids and 180°F using a hot surface temperature of 600°F and 600 psi peak pressure for 30 milliseconds.

The temperature histories through the sheet thickness, shown in Figure 22, also support the concept of a steam layer near the hot surface of the sheet. The temperature at the one-eighth basis weight point measured from the hot surface rapidly reaches temperatures above 212°F, which persist until the end of the nip. Peak temperatures in this region reach 340°F about two-thirds of the way through the nip residence time. However, temperatures at the middle and the cool side of the sheet rise more slowly and do not reach the levels observed on the hot side of the sheet. The back one-eighth of the sheet reaches 212°F only at the end of the nip. Therefore, it is not likely that steam is present throughout the sheet until late in the nip.

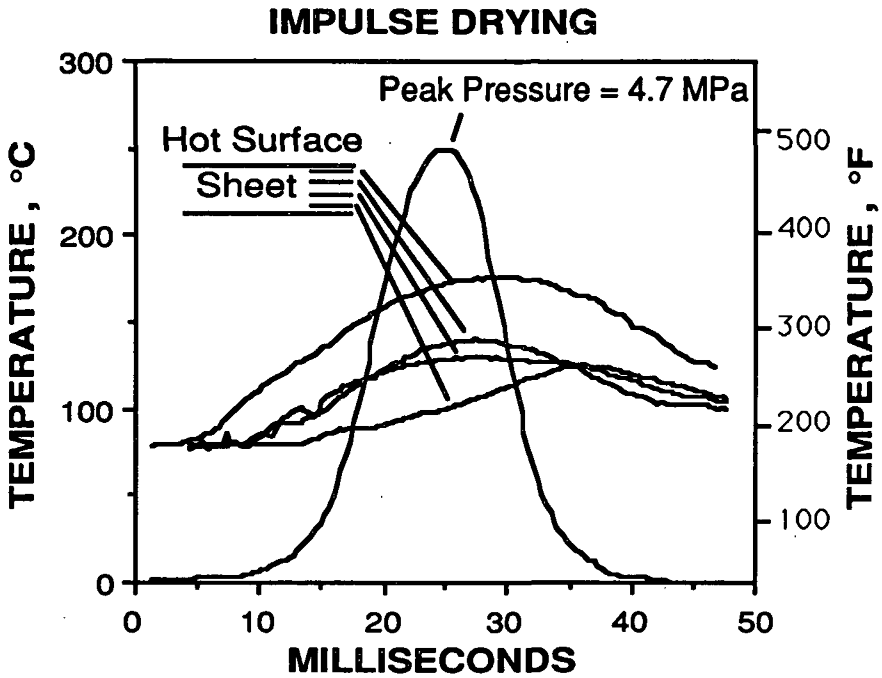


Figure 22. Sheet internal temperature histories observed during impulse drying of a 125 grams per square meter kraft linerboard sheet initially at 35% solids and 180°F using a hot surface temperature of 600°F and 600 psi peak pressure for 30 milliseconds.

The decline in temperature as pressure decreases after midnip is probably due to water flashing from fine pores in the sheet structure and condensing in the cooler regions of the sheet. In Figure 22, the three thermocouples closest to the hot side of the sheet all register declines in temperature after midnip, even though the sheet is still under pressure and receiving heat from the metal surface, as may be seen by comparing the heat flux data in Figure 21. This rapid exchange of heat between the hot side of the sheet and the cooler back side again indicates a vapor-filled region to support intense evaporation/condensation heat transfer across the sheet thickness.

The differences in water removal mechanisms between wet pressing and impulse drying are also apparent in the internal deformations of the sheet. Wet pressing removes water by web compression, which causes a reduction in the void fraction of the sheet and expulsion of the water and air which may be occupying the voids. A typical plot of the void fraction history during a wet pressing event as calculated from internal sheet caliper data is shown in Figure 23. For this 35% solids sheet, the web will reach saturation at a void fraction of 0.74; the void fraction at the end of the nip agrees with the gravimetrically measured 40% solids. The void fraction profile through the sheet reflects sheet stratification due to shear forces compacting the fibers on the water-receiver side of the sheet, a phenomenon which has been described in detail by MacGregor (16).

In contrast, the impulse dried sheet shows a rapid decrease in void fraction in the 25% of the sheet thickness nearest to the hot surface early in the nip (Figure 24). This decease in void fraction occurs at the same time the peak heat flux and surface layer temperatures are increasing. The lower three-quarters of the sheet thickness is much less compacted than during the corresponding wet pressing event (Figure 23) and, in fact, is compressed to void fractions only slightly lower than saturation. These data suggest that liquid water is evaporating from the large voids in the region of the sheet near the hot surface, accompanied by the compression of the sheet structure as steam leaves the region. The cooler portion of the sheet experiences liquid water flow in response to the vapor generation, with only a small reduction in void fraction.

The upper one-quarter of the sheet experiences a final reduction in void fraction at the end of the nip, probably due to flashing of superheated water from very small pores in the sheet. The flashing produces the collapse of the fine structure of fibers

Figure 23. *Void fraction changes during wet pressing calculated from caliper data measured by the eddy current transducer/copper mesh target technique (7). Wet pressing at 85°F using a haversine pressure pulse with a peak pressure of 600 psi for 30 milliseconds. Sheet was 125 grams per square meter kraft linerboard initially at 35% solids.*

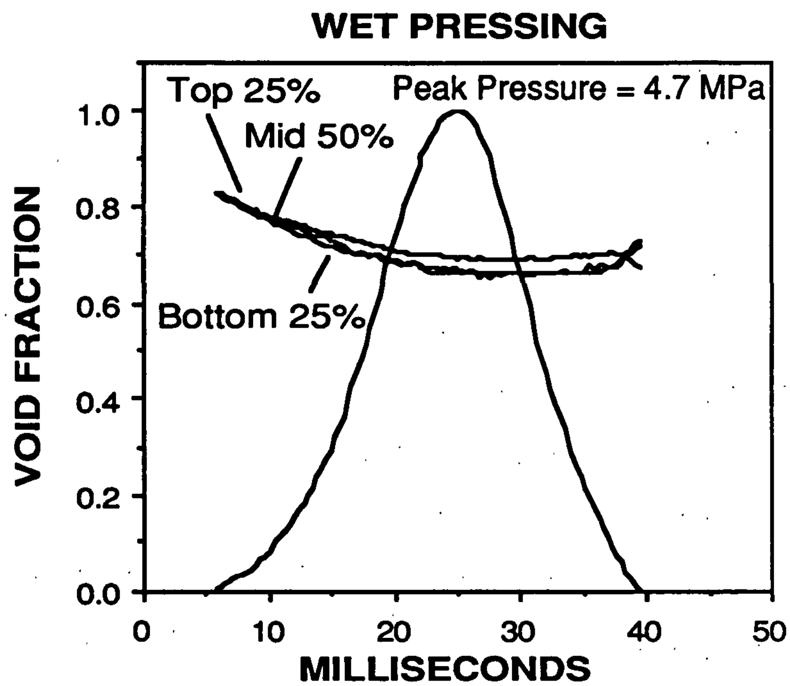
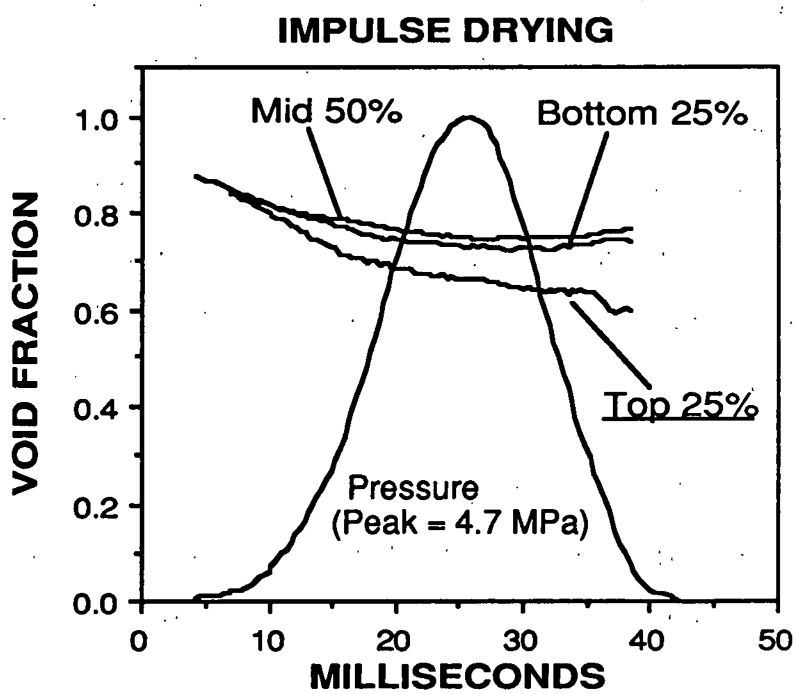


Figure 24. *Void fraction changes observed during impulse drying of a 125 grams per square meter kraft linerboard sheet initially at 35% solids and 180°F using a hot surface temperature of 600°F and 600 psi peak pressure for 30 milliseconds.*



near the hot surface of the sheet, and contributes to the decline in temperature seen in Figure 22. At the end of the nip, the sheet has been stratified with a dense layer near the hot surface and relatively bulky material in the middle and the cold side of the sheet. This density profile can have important consequences in the development of sheet properties, as was reviewed above, in addition to providing evidence for the presence of new dewatering and densification mechanisms during impulse drying.

These data provide evidence for an overall mechanistic picture of impulse drying, represented in Figure 25. High pressure steam is produced in the web near the hot surface and displaces liquid water from the sheet. Meanwhile, high temperatures near the sheet surface promote densification, with particularly emphatic effects on high yield furnishes. The cooler portions of the sheet regain bulk as hot water flashes to steam as pressure is released at the end of the nip.

Practical Consequences of Impulse Drying Mechanisms

The measurements of water removal in the liquid and vapor phase in Figure 20 may be converted into energy demand by calculating a simple energy balance around the sheet. In this study, the assumption has been made that all the water in the sheet is heated to 212°F and that all vapor is formed at one atmosphere pressure. These assumed sheet conditions lead to a calculation of energy use which is known to be conservative (higher than would be observed on an actual machine), as much of the water is displaced before it is heated to a high temperature (8).

IMPLEMENTATION

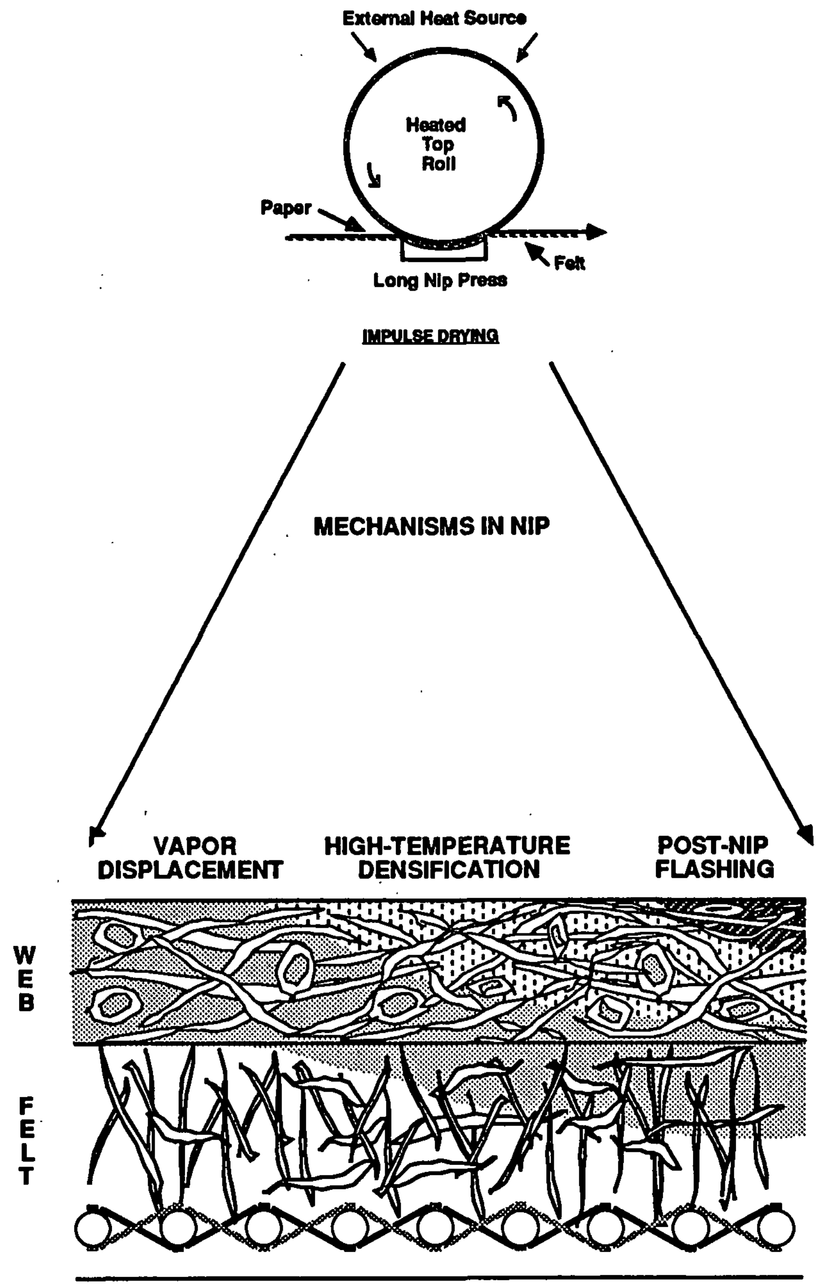


Figure 25. Water removal and densification mechanisms during impulse drying. High pressure steam produced in the web near the hot surface displaces liquid water from the sheet. Meanwhile, high temperatures near the sheet surface promote densification. The cooler portions of the sheet regain bulk as hot water flashes as pressure is released at the end of the nip.

The energy use data show that between 200 and 1000 BTUs are required to remove each pound of water from linerboard (Figure 26). This may be compared with conventional cylinder drying, which requires 1600 to 1800 BTUs per pound on modern machines. The decline in energy requirement as wetter sheets are impulse dried which was reported previously (Figures 13 and 14) continues down to 25% solids, reaching a minimum of 200 BTUs per pound.

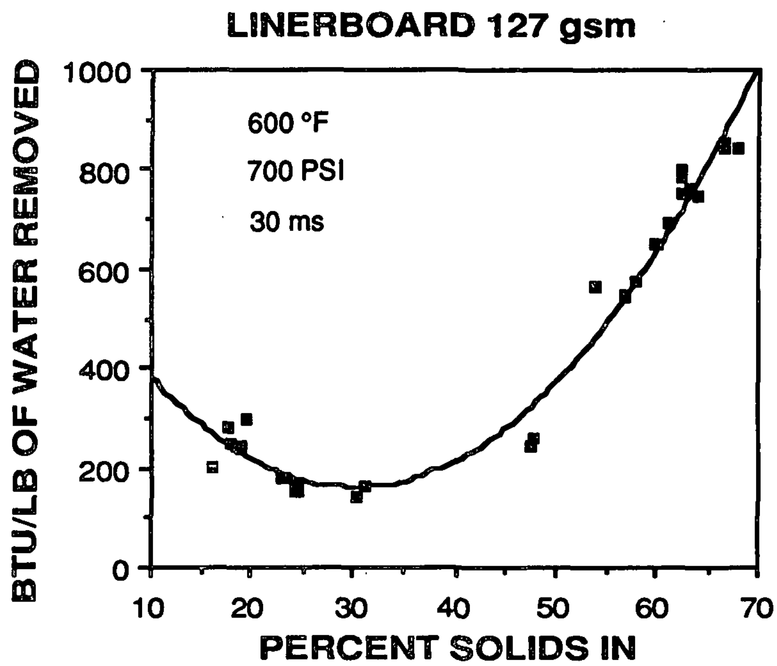


Figure 26. Specific energy use for linerboard. Specific energy as BTUs per pound of total water removed during impulse drying, as calculated using the lithium chloride tracer method. All data for 127 grams per square meter sheets preheated to 180°F before impulse drying. Impulse drying performed at 600°F at a peak pressure of 700 psi for a nip residence time of 30 milliseconds. Data for sheets drier than 58% solids were taken on the reverse side of a previously impulse dried sheet.

A single impulse drying event will leave some water in the sheet; about 0.55 pound of water per pound of fiber remains in the case of 35% solids linerboard. This remaining water would probably be evaporated using conventional cylinder dryers. The energy efficiency of the combined system of impulse drying and conventional drying can be calculated if some assumptions are made about the paper machine system. Figure 27 shows the total energy requirement for an impulse drying plus cylinder drying system on a hypothetical linerboard machine. Conventional drying requirements were assumed to be 1600 BTUs per pound of water removed, with impulse drying energy requirements taken from Figure 26 increased by a factor of 1.4 in an attempt to account for machine efficiency.

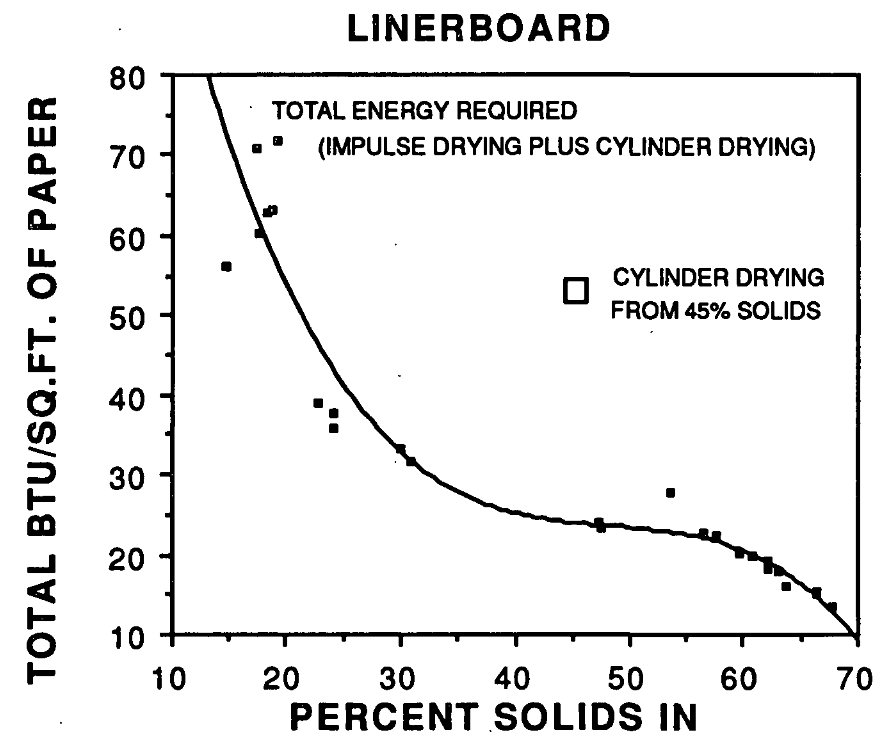
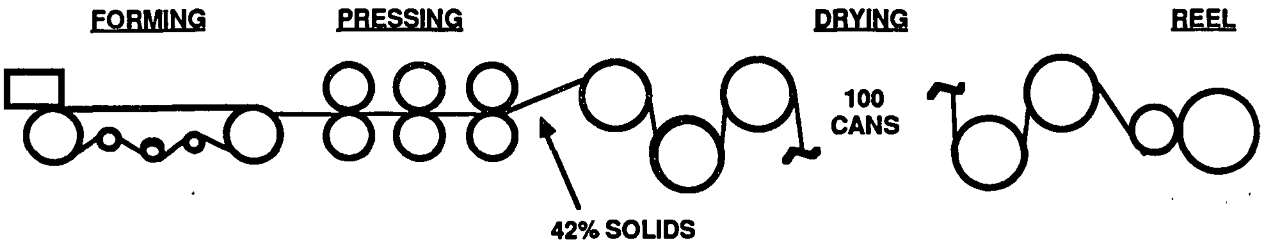


Figure 27. Total energy use for impulse drying plus final cylinder drying for linerboard. Energy use as BTUs per square foot of linerboard dried to 94% final sheet solids at the reel. Impulse drying energy use estimated as 1.4 times the specific energy use (BTU/lb) shown in the previous Figure. Conventional drying energy costs were assumed to be 1600 BTUs per pound of water removed. All data for 127 grams per square meter sheets preheated to 180°F before impulse drying. Impulse drying performed at 600°F at a peak pressure of 700 psi for a nip residence time of 30 milliseconds.

For this possible linerboard machine, impulse drying is found to require half as much energy per square foot of paper dried as conventional drying for sheets entering the impulse dryer at 35% solids. Impulse drying could begin using sheets as wet as 20% solids before energy use equals conventional levels. These results are important because the lowest capital cost configuration for impulse drying may be in the third press (35% solids) position, where most wide nip presses have been installed to date.

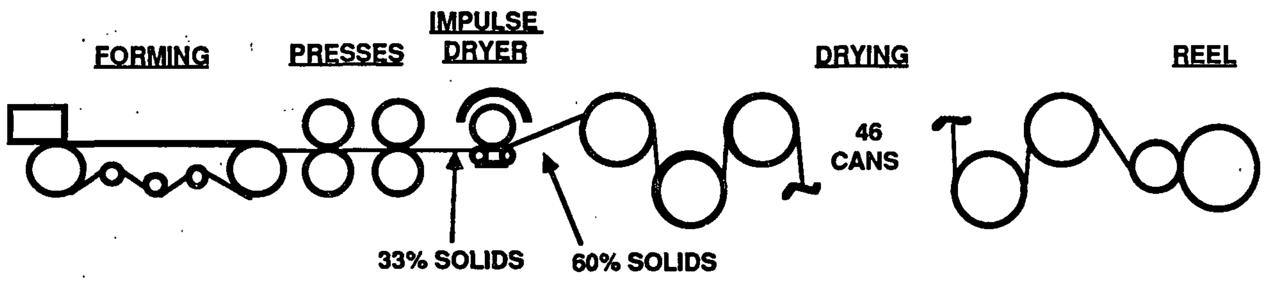
The effects of impulse drying on the configuration of a hypothetical linerboard machine before and after a third-press rebuild to implement impulse drying are shown in Figure 28. These calculations were based on 125 grams per square meter linerboard being produced at 2000 feet per minute on a machine with five-foot diameter cylinder dryers. A cylinder drying rate of 5 pounds of water evaporated per hour per square foot of heat transfer surface was assumed in the calculations. The energy use conditions are those used to construct Figure 27, as described in the previous paragraph. Calculations indicate that if the third press of this machine were rebuilt as an impulse dryer, the machine would require half the cylinder dryers of the original machine, and would consume about one third less energy.

A fifty percent increase in sheet density would be expected, which would potentially allow increases in pulp yield and decreases in refining intensity. Energy saved in pulping and refining could equal or exceed the savings from changes in the drying process, if even 15% substitution of high yield pulps for 50% yield kraft pulp is possible, as shown in Figure 29.



DRYING ENERGY = 3.8 MILLION BTU/TON

SHEET DENSITY = 0.62



DRYING ENERGY = 2.3 MILLION BTU/TON

SHEET DENSITY = 0.96

Figure 28. Overall machine configuration changes possible with impulse drying. Calculations based on 125 grams per square meter linerboard produced at 2000 ft/minute, with conventional 5 foot diameter cylinder dryers. A cylinder drying rate of 5 pounds of water evaporated per hour per square foot of heat transfer surface was assumed in the calculations. Conventional drying energy costs were assumed to be 1600 BTUs per pound of water removed. All data for 127 grams per square meter sheets preheated to 180°F before impulse drying. Impulse drying performed at 600°F at a peak pressure of 700 psi for a nip residence time of 30 milliseconds.

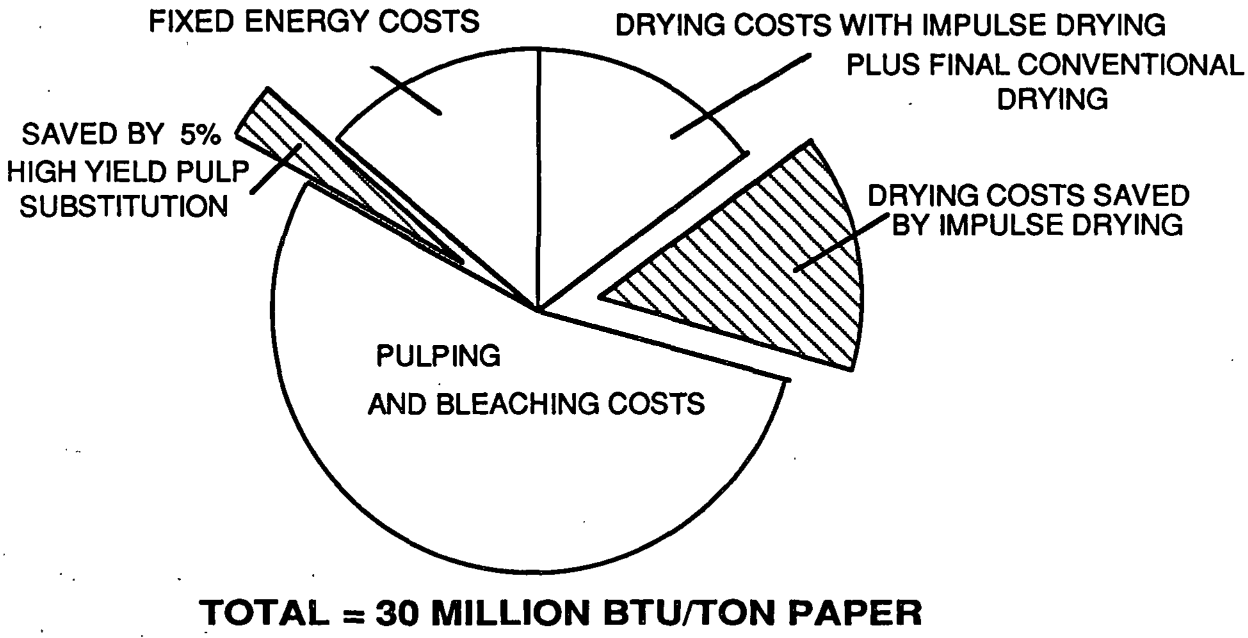


Figure 29. Potential energy savings from impulse drying.

Heat Flux Effects

The heat flux measurement shown in Figure 21 is part of a larger study of the fundamentals of heat transfer in impulse drying underway at The Institute of Paper Chemistry. The major effort in this area is in doctoral thesis research by G. Rudemiller, which was begun in August, 1987. A limited amount of data have been obtained in the funded research program to help understand specific process performance questions. More comprehensive heat flux data will be obtained over the next twelve months through Rudemiller's thesis and as part of the present project.

Effects of Pressure Pulse Shape on Impulse Drying Heat Flux

The bench scale electrohydraulic press equipment produces a wide range of controllable, reproducible pressure pulses. However, its characteristic pulse shape includes ten to fifteen milliseconds of low pressure precontact at between two and ten psi. This type of precontact would be produced on a roll press by a few inches of wrap of the sheet on the roll.

Low pressure precontact significantly changes the shape of the instantaneous heat flux history over time, although the total amount of heat transferred is similar. Figure 30 presents a comparison between the electrohydraulic press and the earlier drop weight test equipment used in Burton's thesis work (7). The drop weight device produces a very sharp peak in heat flux, which may reach 2.5 million BTUs per hour per square foot. The electrohydraulic press produces a low level of heat flux as the sheet and hot surface contact at low pressures, followed by a slower rise to a peak heat flux of about 1.8 million BTUs per hour per square foot.

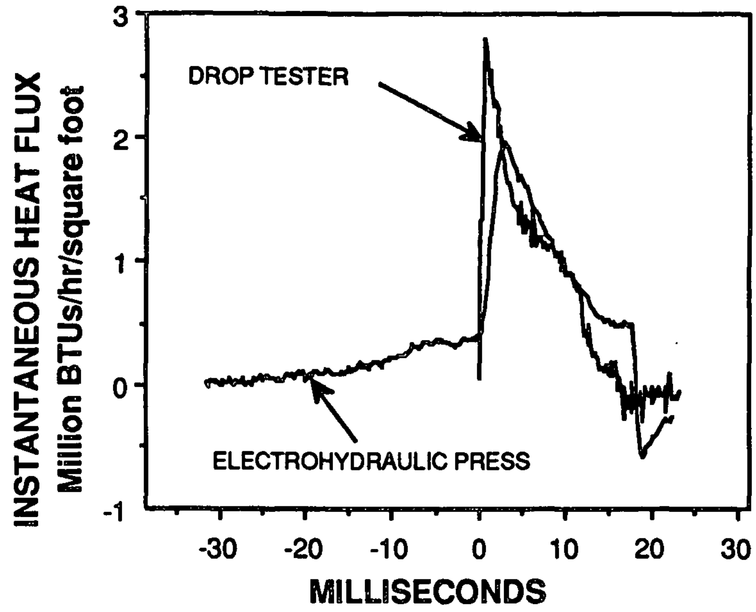


Figure 30. Effects of pressure pulse shape on the instantaneous heat flux to the sheet as measured by the surface junction thermocouple technique. Kraft linerboard at 125 grams per square meter basis weight, impulse dried for 15 milliseconds at 700 psi peak pressure and 600°F. Initial conditions for the sheets were 50% solids and 80°F. The MTS electrohydraulic press control system leads to 15 to 20 milliseconds of precontact between the hot surface and the sheet; the drop weight tester produces no precontact.

The differences in pressure pulse shape which produced these heat flux behaviors are shown in Figure 31. Although the main portion of the pressure pulse is very similar for the two devices in terms of the rate of pressure rise, the peak pressure achieved, and the rate of decline, the electrohydraulic press has both precontact and a more gradual rate of rise in the first two milliseconds of the nip. Precontact between the sheet and the hot surface would thus be expected to produce vapor in the sheet earlier, leading to improved water removal. Precontact effects will receive further attention in future work.

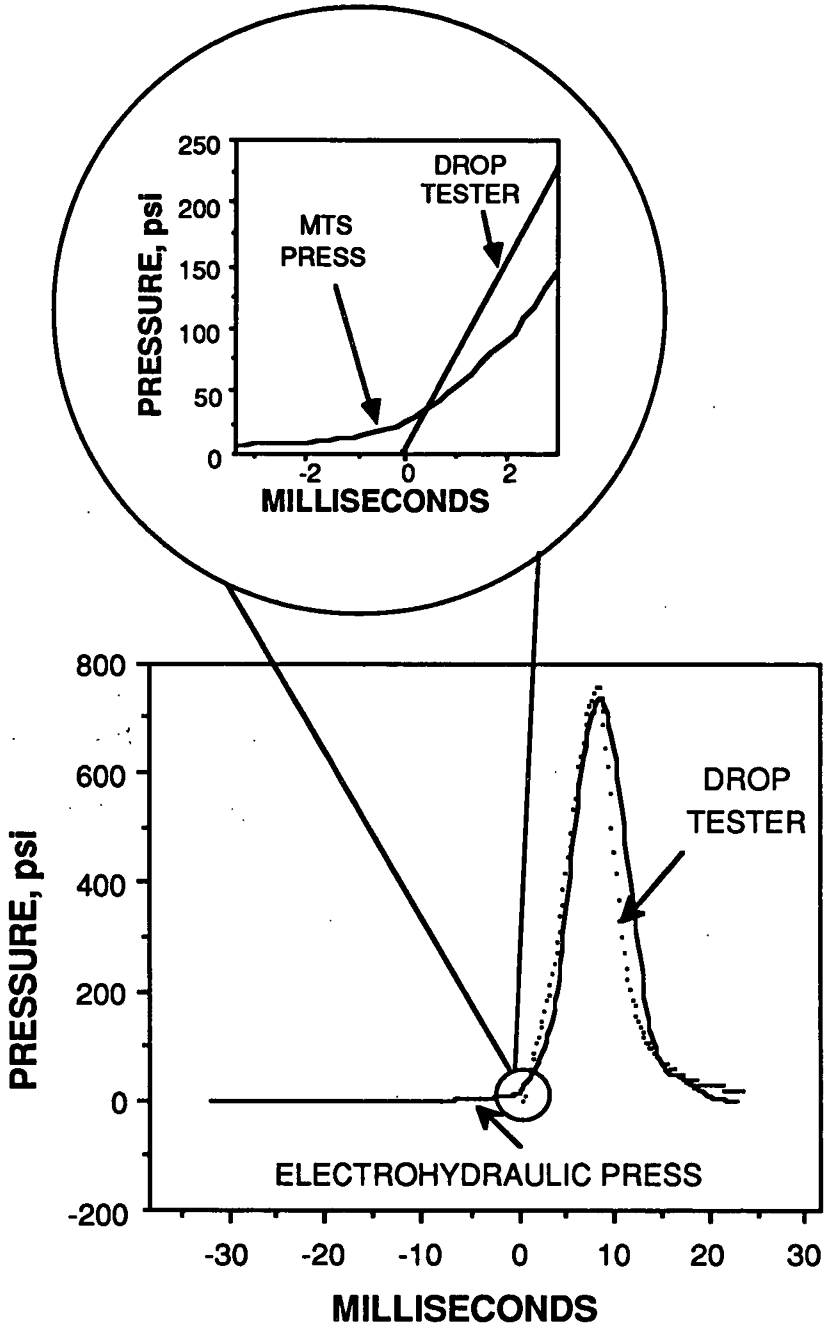


Figure 31. Pressure pulse shapes produced by the MTS electrohydraulic press and by the drop weight tester. Kraft linerboard at 125 grams per square meter basis weight, impulse dried for 15 milliseconds at 700 psi peak pressure and 600°F. Initial conditions for the sheets were 50% solids and 80°F. The MTS electrohydraulic press control system leads to 15 to 20 milliseconds of precontact between the hot surface and the sheet; the drop weight tester produces no precontact.

Effects of Nip Residence Time on Impulse Drying Heat Flux

The effect of nip residence time on impulse drying is an important issue, as nip length would be a hardware parameter which could not easily be changed once a machine was built. Earlier results (2) showed that water removal rates in impulse drying tend to vary with the reciprocal of the square root of the nip residence time. Thus, water is removed faster in shorter nips, although the total amount of water removed (water removal rate times total time in the nip) will increase as the square root of nip residence time.

The reason for this behavior is probably due to the way in which heat is released into the sheet during an impulse drying event. Two processes may influence heat release during impulse drying. Early in the nip, water is readily available at the sheet surface, and boiling appears to be influenced primarily by thermodynamic conditions such as the rate of pressure application discussed in connection with Figures 30 and 31. The heat flux curve characteristically peaks early in the nip, frequently before maximum pressure is reached. This peak heat flux could represent either a thermodynamic limit or a limit in water availability. To distinguish between these two possibilities, a series of experiments was run to determine how the heat flux history in the nip changes as the time in the nip is extended.

Figures 32 through 34 compare the heat fluxes observed under the same peak pressure and temperature conditions as a square-wave pressure pulse is extended from 40 to 310 milliseconds; the three heat flux plots are overlaid in Figure 35 for easier comparison. Extending the nip residence time has little effect on the time of peak heat flux or on the magnitude of peak heat flux. This suggests that the limit in heat flux is

Figure 32. Effects of nip residence time on heat flux to the sheet. Instantaneous heat flux measured by the surface junction thermocouple technique. Data for 125 grams per square meter linerboard sheets initially at 40% solids presteamed to 180°F. Sheets impulse dried for 40 milliseconds at 500 psi peak pressure and 600°F hot surface temperature.

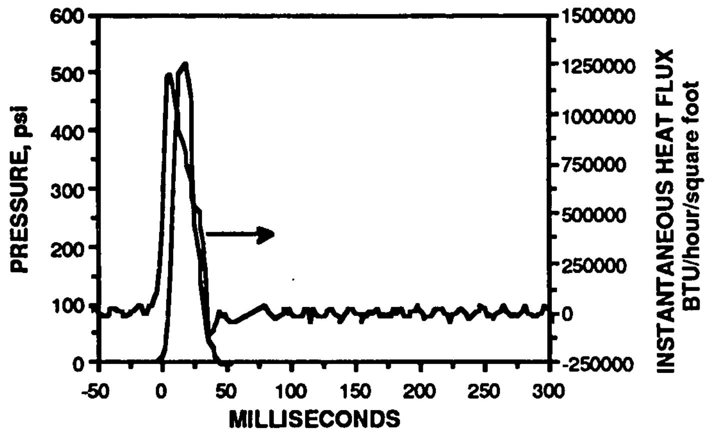


Figure 33. Effects of nip residence time on heat flux to the sheet. Instantaneous heat flux measured by the surface junction thermocouple technique. Data for 125 grams per square meter linerboard sheets initially at 40% solids presteamed to 180°F. Sheets impulse dried for 140 milliseconds at 500 psi peak pressure and 600°F hot surface temperature.

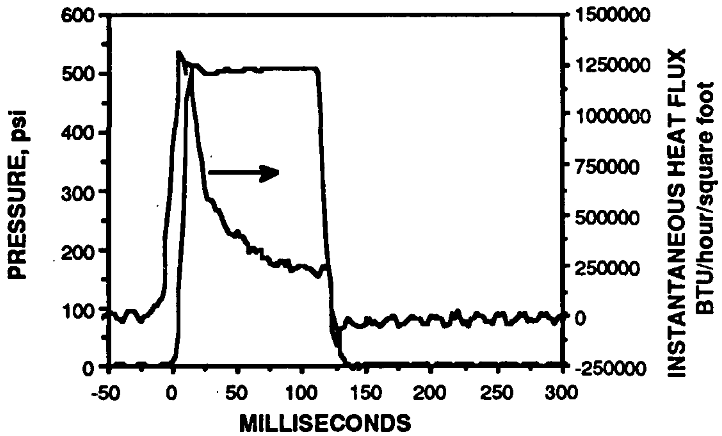
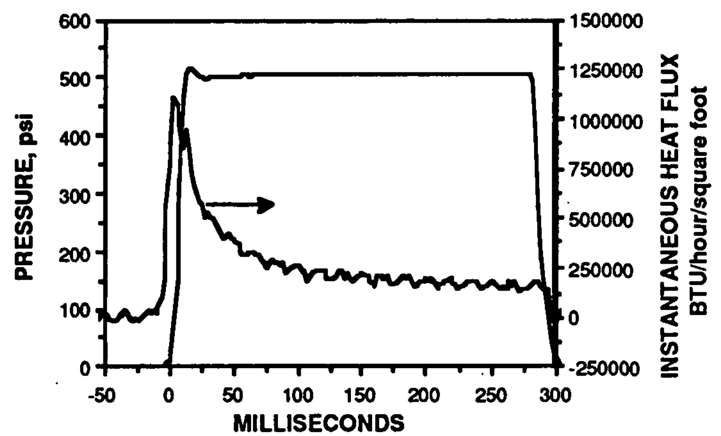


Figure 34. Effects of nip residence time on heat flux to the sheet. Instantaneous heat flux measured by the surface junction thermocouple technique. Data for 125 grams per square meter linerboard sheets initially at 40% solids presteamed to 180°F. Sheets impulse dried for 310 milliseconds at 500 psi peak pressure and 600°F hot surface temperature.



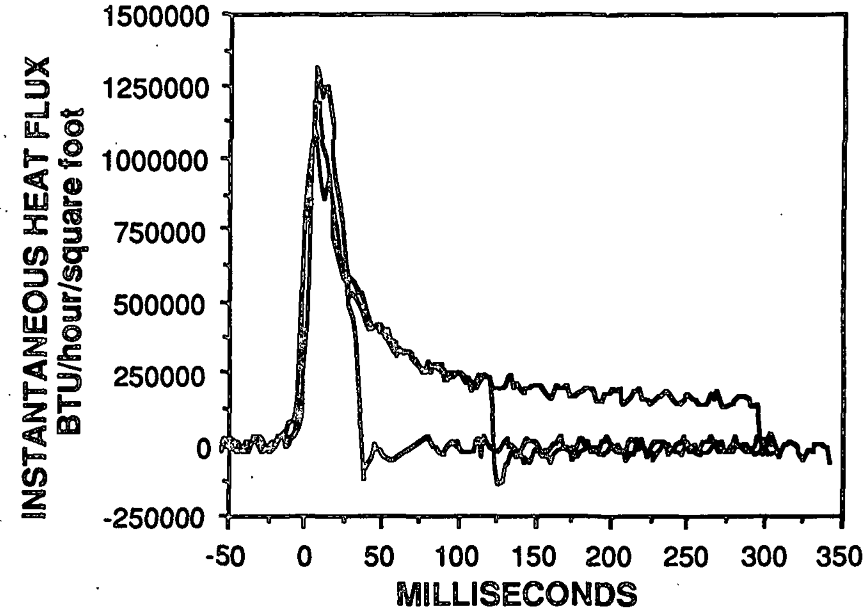


Figure 35. Effects of nip residence time on heat flux to the sheet, with 40, 140 and 310 millisecond data superimposed for comparison. Instantaneous heat flux measured by the surface junction thermocouple technique. Data for 125 grams per square meter linerboard sheets initially at 40% solids pre-steamed to 180°F. Sheets impulse dried at 500 psi peak pressure and 600°F hot surface temperature.

actually a limit in water availability. The heat flux decays to about one-fifth of the peak heat flux value (250,000 BTUs per hour per square foot) after 100 milliseconds. Further declines in heat flux are very slow. The high heat fluxes indicate that a relatively stable boiling-condensation cycle is still in operation late in the nip.

The amount of energy transferred to the sheet will tend to increase as the square root of nip residence time, just as the water removal rate has been observed to do empirically. As a result, the BTUs required to remove each pound of water are only weakly dependent on nip residence time. From a specific energy use point of view, nip residence time is not an important variable, but the total energy transfer to the sheet will increase as the square root of the nip residence time. Nip length and the heating capability of an impulse dryer heating system are thus related variables.

Effects of Sheet Moisture Content on Impulse Drying Heat Flux

Since the location of the peak heat flux and the postpeak heat transfer history appear to be dominated by water availability, it is interesting to examine the effects of changing sheet moisture content on the prepeak heat flux behavior. Figure 36 shows the heat flux histories observed as sheet moisture ratio is increased from 1 pound of water per pound of fiber (50% solids) to 4 (20% solids). Wetter sheets allow the boiling process to begin earlier in the nip, as less pressure is required to force water to the sheet surface. The peak heat flux also tends to be higher with wetter sheets, again pointing to water availability as the limiting factor. The decline in heat flux late in the nip followed similar trends, indicating that sheet conditions over the region where the evaporation/condensation heat flux cycle is active become equalized early in the nip, whatever the initial sheet moisture content.

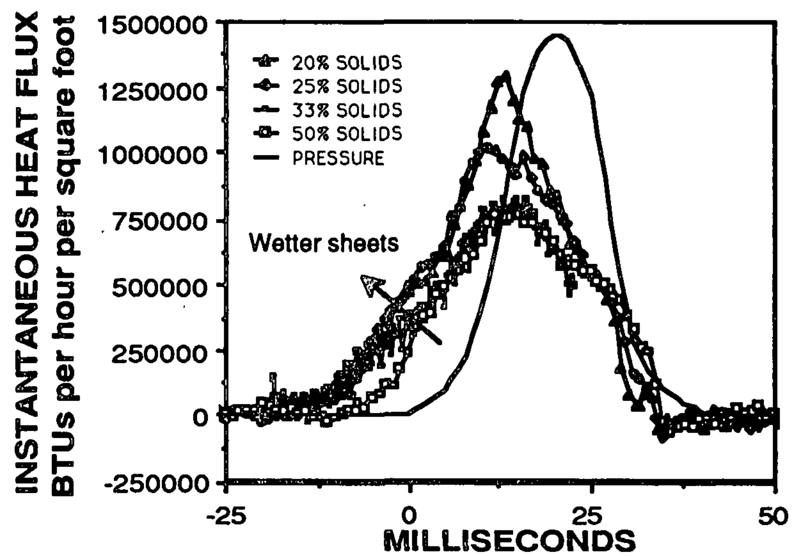


Figure 36. Effects of sheet moisture content on heat flux to the sheet. Instantaneous heat flux measured by the surface junction thermocouple technique. Data for 125 grams per square meter linerboard sheets initially at 25% and 50% solids presteamed to 180°F. Sheets impulse dried for 40 milliseconds at 500 psi peak pressure and 600°F hot surface temperature.

Further work on heat flux fundamentals are planned to clarify the effects of temperature, pressure, refining and furnish type on the heat transfer performance of impulse drying.

Process Limitations (Delamination)

The phenomenon of delamination during intense impulse drying of moderate to heavy basis weight sheets was reported in earlier work at The Institute of Paper Chemistry. Burton (17) observed delamination in an unbleached softwood kraft pulp beaten to 550 mL CSF at basis weights of 100 grams per square meter and heavier. Lower basis weight sheets (40 to 50 grams per square meter) of this furnish did not exhibit blistering or delamination. These observations are consistent with the probable mechanisms of impulse drying. Very thick or highly refined sheets will exhibit greater resistance to the flow of vapor and liquid than thin or coarse webs. If the flow resistance of the web becomes so large that the high pressure steam produced during impulse drying cannot dissipate before the mechanical restraint on the sheet is relieved, the sheet may not be strong enough to sustain the pressurized vapor. Blistering or delamination may then result.

More recent project work (2) indicated that several commercially important grades, including lightweight southern pine linerboard, lightweight coating rawstock, writing papers and newsprint showed excellent resistance to delamination. None of these materials delaminated at commercially useful temperatures (below 700°F), although delamination could be produced in all of these furnishes if intense enough conditions were applied. The sheets used for this study were all produced from realistic furnish samples obtained from commercial mills, and so should reasonably predict performance of these materials in practice. It is probable, however, that commercially important furnishes exist which are more susceptible to delamination than those previously studied. At present, there is no way to predict the delamination potential of a furnish without impulse drying actual samples of the material.

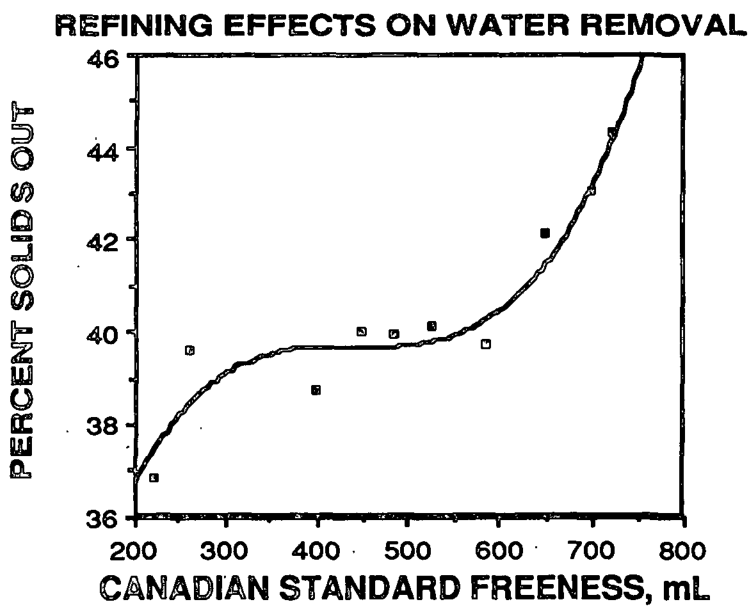
An improved understanding of delamination will be essential so that the impulse drying process can accommodate as many furnish types as possible. Work on the mechanisms of delamination is currently underway in three Master's research problems at the Institute, supported by increased emphasis on delamination in the funded research work.

The work on delamination available to date involved a limited study to determine whether increasing the flow resistance of southern pine kraft linerboard by refining would produce delamination and, if so, how much refining would be required to induce the problem. A secondary objective of the study was to determine which laboratory test would best detect the onset of delamination, as visual examination is not always reliable as small blisters can heal during subsequent drying.

For this experiment, a sample of the southern pine unbleached kraft pulp used in earlier work on this project was refined in a Valley beater. Samples were extracted over time to achieve a series of samples separated by 50 mL intervals in Canadian Standard Freeness. The pulp samples were then made up at 200 grams per square meter basis weight, prepressed to 35% solids, and impulse dried without preheating at 700°F and 400 psi peak pressure for 30 milliseconds. Delamination was noted visually below 600 mL CSF, and later confirmed by z-direction tensile strength tests.

The increasing flow resistance of the web with refining is suggested by Figure 37. Previous work was done at a refining level of 650 mL CSF, at which impulse drying under these conditions would produce a final sheet solids of about 41% solids. Reducing refining toward 750 mL CSF improves the final solids level by about three percentage points; increasing refining towards 350 mL CSF produces only a minor reduction in water removal. Sheets of this furnish produced from 650 mL CSF pulp do not delaminate, but a 50 mL decrease in freeness will produce delamination. The change in final solids level between these refining levels is minimal. The problem is therefore probably not produced by flow resistance alone, but may also involve changes in the amount of heat released to the sheet. Changing the sheet pore structure and pore size distributions by refining might influence both the boiling and water resupply mechanisms of impulse drying, resulting in increased steam production. This question requires further study in the coming year.

Figure 37. Water removal observed during a web delamination study on 200 grams per square meter linerboard initially at 35% solids. All impulse drying was done at 700°F, 400 psi peak pressure and 30 milliseconds. Delamination was observed for all samples refined below 600 mLCSF.



The effects of delamination on internal bond strength or z-direction tensile strength are shown in Figure 38. Internal bonding improves with refining down to 600 mL CSF, after which delamination begins to reduce bonding. Impulse drying increases internal bonding by almost 20 percent when compared with a pressed and conventionally dried sample at 650 mL CSF, which suggests that no "incipient" delamination was underway at that condition.

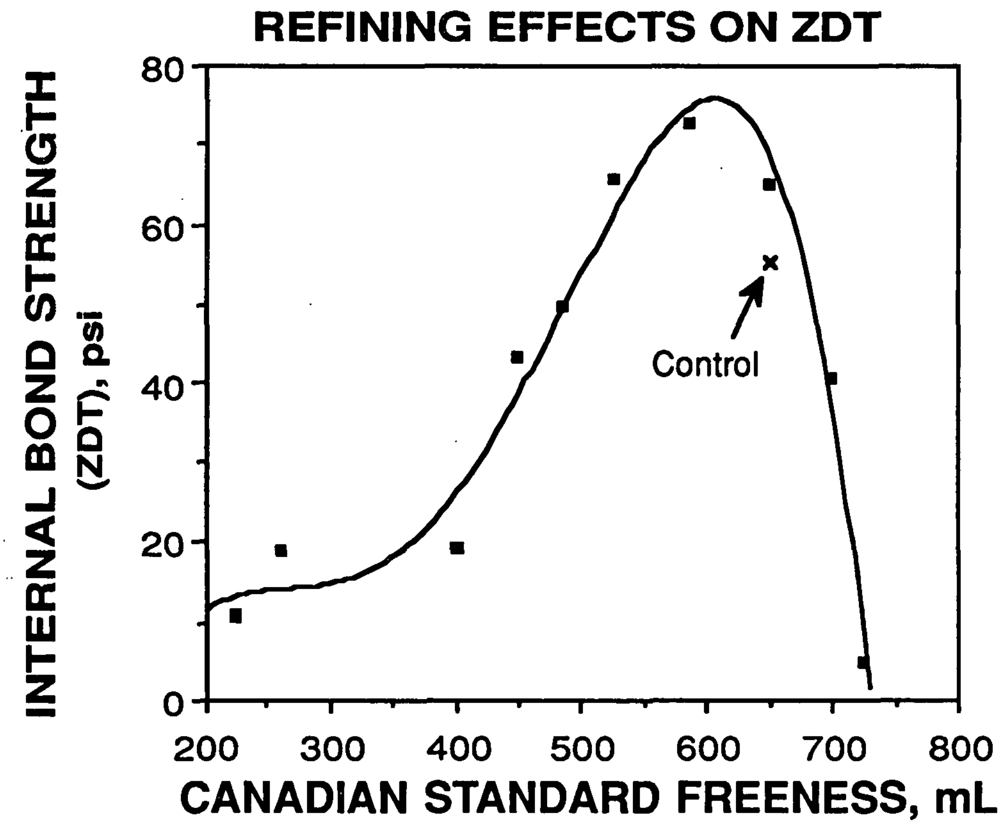


Figure 38. Internal bond strength measurements indicating web delamination in 200 grams per square meter linerboard initially at 35% solids. All impulse drying was done at 700°F, 400 psi peak pressure and 30 milliseconds. Delamination was observed for all samples refined below 600 mLCSF.

Apparent density (Figure 39) followed similar trends, but does not give as clear a picture of the onset of delamination as the internal bond strength test. The density data would suggest that no loss in average density occurred down to 550 mL CSF, well below the actual delamination limit. Density changes are thus not an adequate diagnostic for delamination.

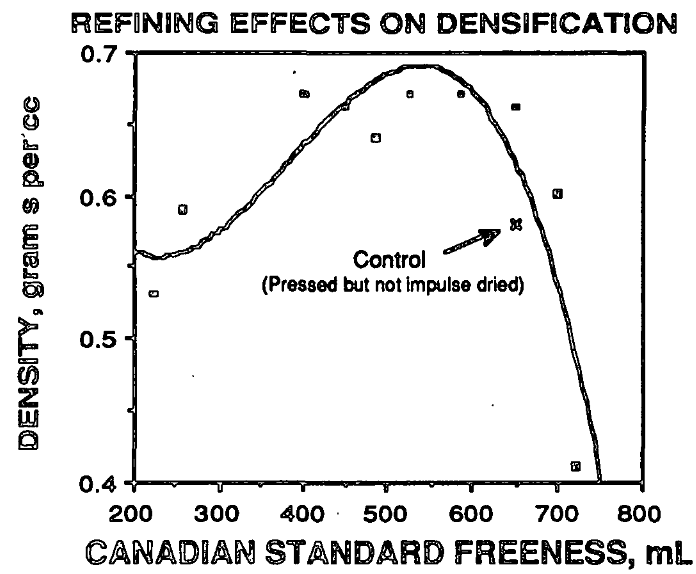


Figure 39. Changes in apparent IPC soft platen density indicating web delamination in 200 grams per square meter linerboard initially at 35% solids. All impulse drying was done at 700°F, 400 psi peak pressure and 30 milliseconds. Delamination was observed for all samples refined below 600 mLCSF.

However, STFI (Figure 40) is sensitive to loss of sheet internal bonding and can give a clear indication of the start of delamination. As STFI is considerably faster and easier to run than the ZDT internal bonding test, it appears to be a very good means to detect delamination. Thus, the previous STFI test work reported in Figure 10 confirms the absence of delamination under the conditions and furnishes used in past project work at The Institute of Paper Chemistry.

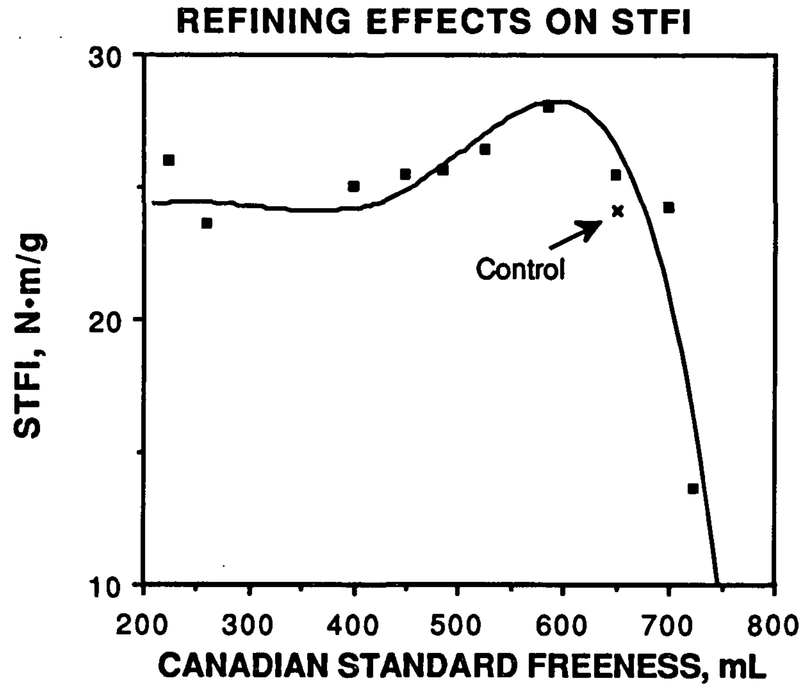


Figure 40. STFI compressive test results for 200 grams per square meter linerboard initially at 35% solids refined to induce delamination. All impulse drying was done at 700°F, 400 psi peak pressure and 30 milliseconds. Delamination was observed for all samples refined below 600 mL CSF.

This preliminary study has thus demonstrated that delamination can be induced by refining. Further work is necessary to understand the heat release, flow resistance, and wet web strength phenomena which appear to govern delamination.

PILOT ROLL IMPULSE DRYER CONSTRUCTION

Goals of Roll Impulse Dryer Construction Work

Construction of a pilot roll impulse dryer was essential in the development of impulse drying, as there are a number of important process and product performance questions which cannot be addressed with the bench-scale geometry and sample size limits. These questions include

1. Will the water removal and densification performance be the same in the roll geometry as in a flat press?

2. What will the energy efficiency of the process be in the roll geometry?

3. Will there be process problems such as sticking or delamination that will develop in a roll geometry?

4. How will the heated roll perform metallurgically under these difficult cyclical conditions? How will felts perform?

5. How will impulse dried sheets perform when they are converted? Large samples are essential to do meaningful evaluations of printing, coating, and the conversion of medium and linerboard to combined board.

To address these questions, The Institute of Paper Chemistry is building a pilot roll impulse dryer with the assistance of a four-year 1.5 million dollar grant from the Department of Energy.

Construction of the First Nip

The pilot roll impulse dryer in its current form is sketched in Figure 41. The ultimate design of the dryer includes two nips; the design of the second nip is now underway with construction scheduled for the first quarter of 1988. A simple press design with two hard rolls has been used, eliminating the mechanical complexity of a wide nip press at the cost of a slow machine speed. Current speed is limited to 350 feet per minute, which can be increased to 700 feet per minute with a simple belt ratio

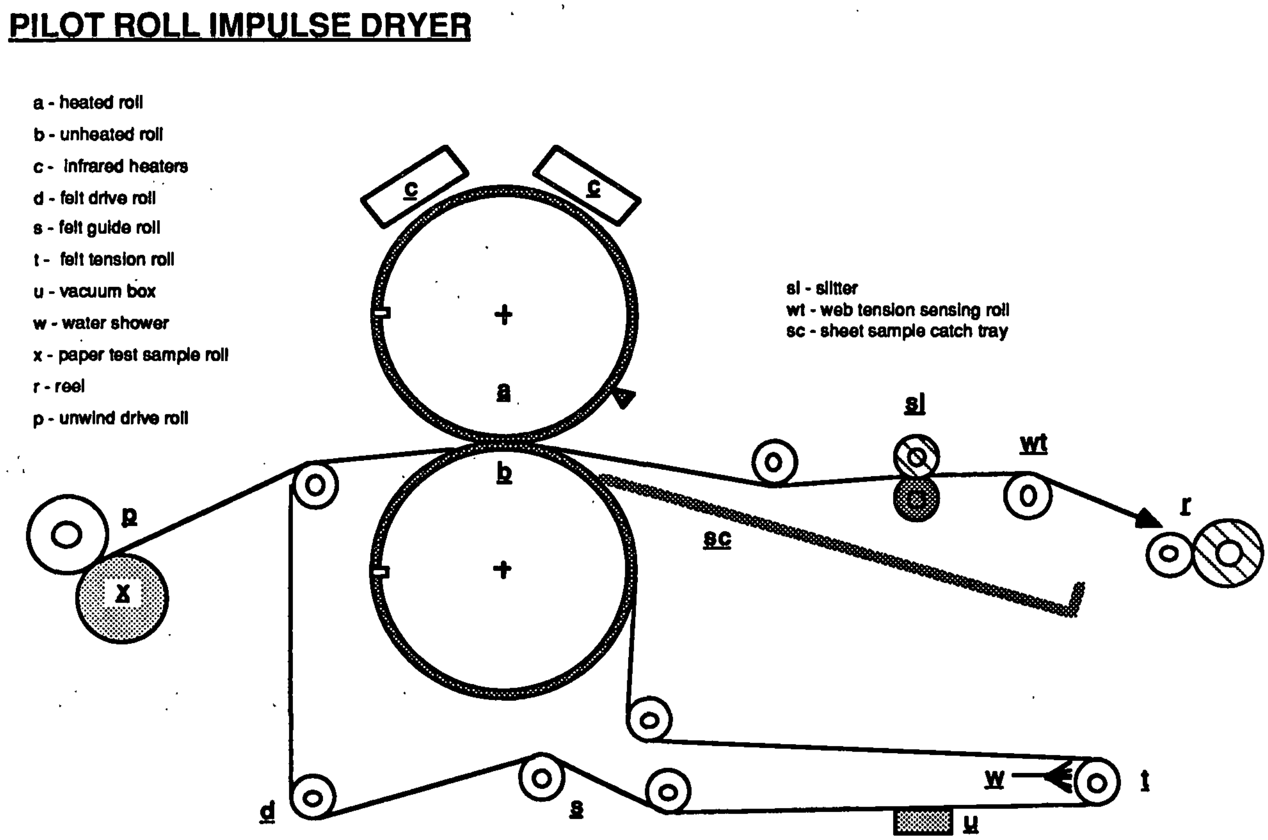


Figure 41. Schematic of the pilot roll impulse dryer first nip and major operating systems in its September, 1987 configuration.

change if needed in later work. The rolls are plain carbon steel with bolted end plates, two feet in diameter and two feet wide, and generally are used to impulse dry one foot wide board samples made on the Institute web former. A hydraulic system can load the rolls up to 1500 pounds per lineal inch over the 24-inch face width.

Electrical infrared heaters provide thermal energy to the upper roll. The heaters have been able to sustain 700°F roll temperatures against wet felts and paper. Heater control in two zones across the roll face is based on signals from surface junction thermocouples in the roll. Heater response time is fast enough that roll surface temperature can be regained within one roll revolution after initial contact with a wet sheet.

Individual rolls are driven from the line-shaft through clutch/brake systems for independent control. Variation in roll surface speeds due to thermal expansion can be compensated for by slippage in the roll clutch as the nip is closed. A surface-driven unwind stand was added during August, 1987, to simplify handling weak wet webs.

The water receiver is a commercial Nomex fiber wet press felt. The felt has an automatic tracking system, automatic tensioning, a lubricating shower, and a vacuum box to remove excess water from the felt. The felt can be conditioned by running the press nip at ambient temperature. Although the machine was designed to run with the sheet overlapping the edge of the felt for protection, the wet felt has tolerated the temperature conditions well without such precautions. The slitters which were included in the design to cut the wet edges from the web before rewinding have not been needed for that purpose.

Instrumentation includes surface junction thermocouples mounted through the hot roll shell which are used for heater control and, eventually, for energy use measurements. Other control instruments are a tachometer on each roll, load cells on each nip loading cylinder, and a transducer for roll rotational position. Machine control is accomplished through a programmable controller donated to the project by Westinghouse. Pressure sensors mounted in the lower roll are used to confirm nip widths and nip residence times. A high-speed data acquisition system records process data so that detailed temperature and pressure histories can be obtained for each test.

Most pilot impulse dryer work before August was done with handsheets or three- to five-foot-long pieces cut from webformer sheets. The sheets were placed on six-foot-long pieces of felt, and the sheet and carrier felt were sent through the nip supported by the machine felt. A sample slide was added as shown in Figure 41 to recover the sheet -fed samples.

PILOT ROLL IMPULSE DRYER EXPERIMENTAL WORK

Initial Operation

The initial physical property data from the new equipment was collected late in April, 1987. Table 3 presents the test values observed from the initial run on 42-lb linerboard, which was impulse dried at 600°F, 400 psi pressure and 100 milliseconds nip residence time. All initial work has been done using a never-dried southern pine kraft linerboard furnish taken from a commercial linerboard mill. This furnish is refined to 650 mL Canadian Standard Freeness before sheet making. Most of the impulse dried test values for this 42-lb product approach the commercial test expectations for 69-lb liner. The magnitudes of the strength increases were similar to those observed in early bench-scale work.

TEST	COMMERCIAL BOARD	IMPULSE DRIED
Burst, psi	105	137
STFI, lb/in	21	32
Ring Crush, lb/6 in	75	125
ZDT, psi	50	99
Density, g/cc	0.69	0.84
lb/point	3.6	4.4

Table 3. Initial performance data from the pilot roll impulse drier. 42 pound per 1000 square foot southern pine linerboard impulse dried at 600°F, 400 psi peak pressure and 100 milliseconds nip residence time on each side of the sheet.

The pilot roll impulse dryer has performed with few problems, and has required only a few minor adjustments. The linerboard grade runs well on the roll press. Sheet release from the hot roll has not been a problem as long as the roll temperature is maintained above 380°F.

The most serious delay-producing problems have resulted from web former operation, not from the roll press. The web former press design (Figure 42) made it extremely difficult to produce 42-lb sheets at solids levels above 25% solids; such wet sheets are very weak and difficult to handle. Numerous web breaks made continuous operation of the roll impulse dryer impossible. A rebuild of the web former press section was completed during August, 1987. We can now produce sheets at 35% solids, which are much easier to handle in roll form without excessive breaks.

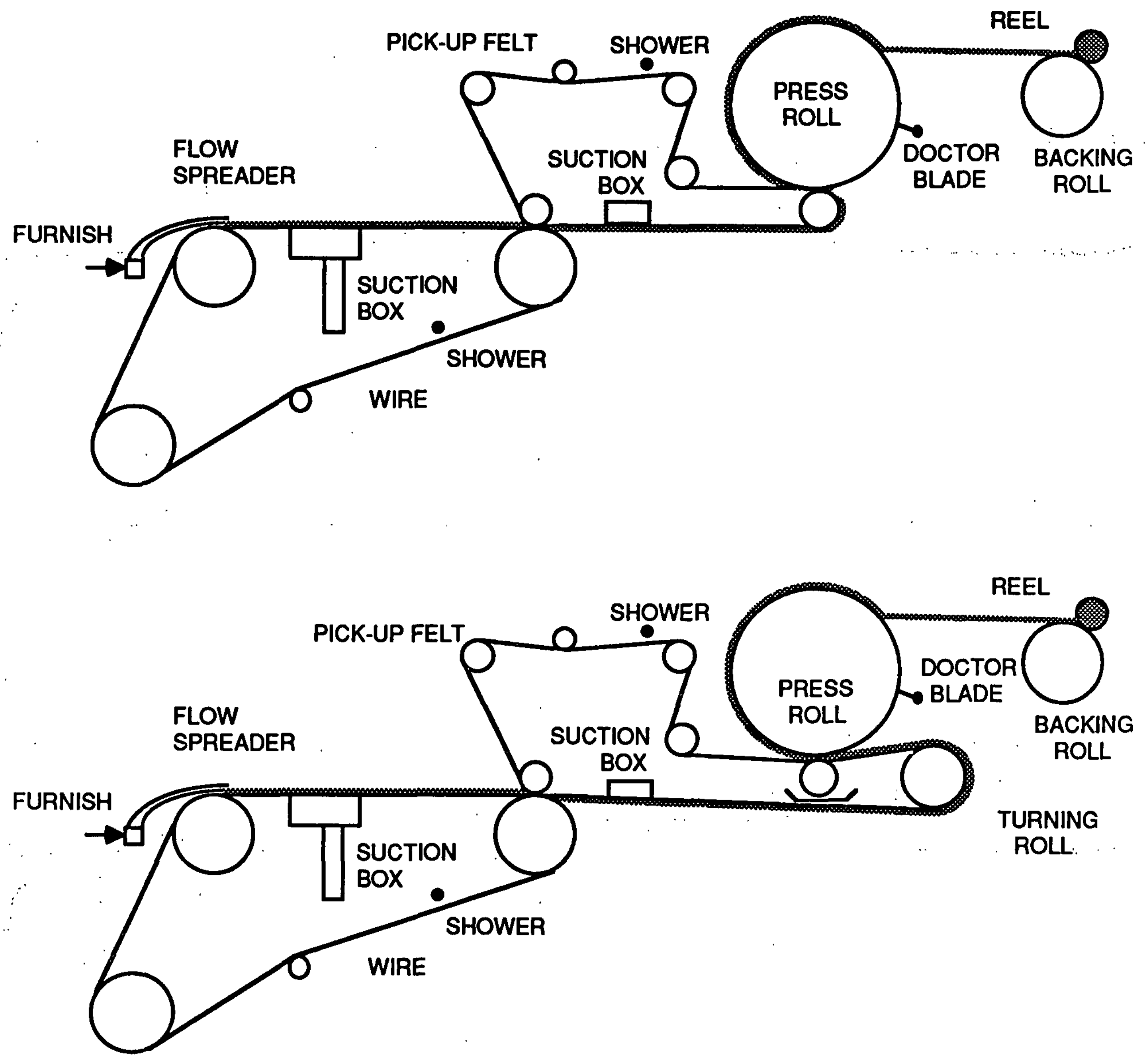


Figure 42. The pilot web former at The Institute of Paper Chemistry before (above) and after press rebuild to improve water removal.

Comparison of Roll Press and Platen Press Performance

The next step in the experimental program was a direct comparison between the roll press and the bench platen press to confirm the validity of the performance results reported in the earlier work. For 42-pound southern pine linerboard, the water removal response of the platen press (MTS) and the roll press are very similar, as shown in Figures 43 through 46. The slightly lower final percent solids occasionally observed on the roll press are probably the result of rewetting, since the sheet can be separated from the felt more rapidly in the platen press geometry than in the sheet-fed roll press. Variation in water removal due to differences between handsheets and web former sheets were greater than variations due to the geometry of impulse drying.

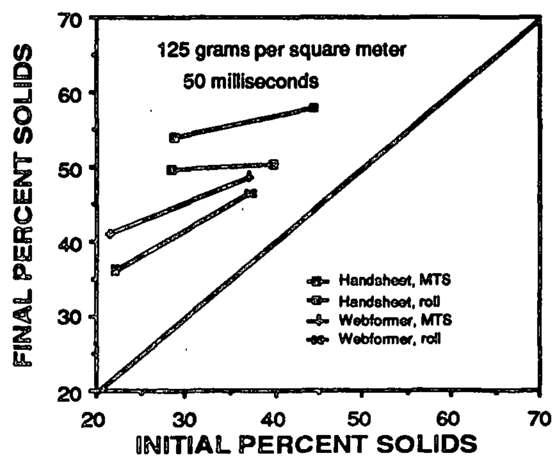


Figure 43. Comparison between the water removal performance of the pilot roll impulse dryer and the electrohydraulic press, and of handsheets and web former sheets. All tests run at 400 psi peak pressure and 500°F. Linerboard sheets initially at room temperature (80°F). 125 grams per square meter sheets impulse dried for 50 milliseconds.

Figure 44. Comparison between the water removal performance of the pilot roll impulse dryer and the electrohydraulic press, and of handsheets and web former sheets. All tests run at 400 psi peak pressure and 500°F. Linerboard sheets initially at room temperature (80°F). 205 grams per square meter sheets impulse dried for 50 milliseconds.

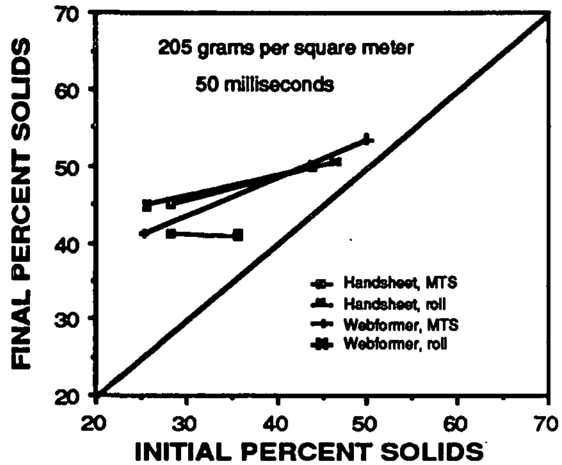


Figure 45. Comparison between the water removal performance of the pilot roll impulse dryer and the electrohydraulic press, and of handsheets and web former sheets. All tests run at 400 psi peak pressure and 500°F. Linerboard sheets initially at room temperature (80°F). 125 grams per square meter sheets impulse dried for 100 milliseconds.

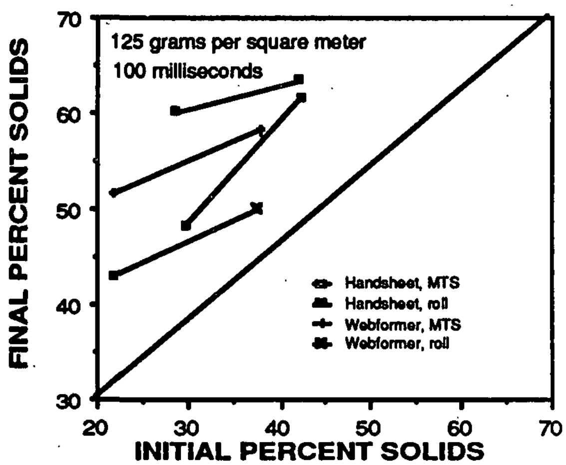
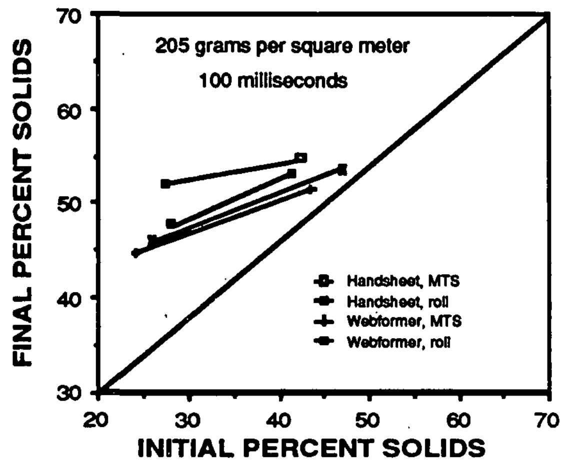
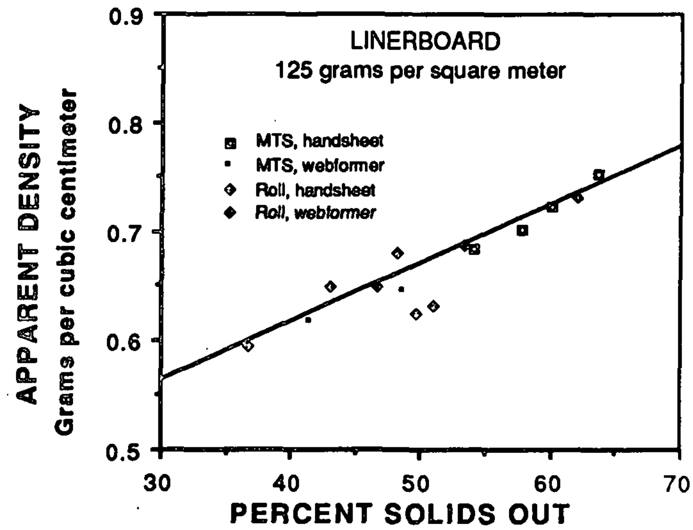


Figure 46. Comparison between the water removal performance of the pilot roll impulse dryer and the electrohydraulic press, and of handsheets and web former sheets. All tests run at 400 psi peak pressure and 500°F. Linerboard sheets initially at room temperature (80°F). 205 grams per square meter sheets impulse dried for 50 milliseconds.



Density variations due to impulse drying geometry were minor. Previous work has shown that impulse drying gives a straight line relationship between density and the percent solids achieved after the nip, with little dependence on the choice of temperature, pressure and nip residence time used to achieve a given solids level. Density development is similarly insensitive to geometry and handsheet/web former sheet variations, as may be seen in Figures 47 and 48.

Figure 47. The density - percent solids relationship effects of impulse drying geometry and sheet type. All tests run at 400 psi peak pressure and 500°F for 50 or 100 milliseconds using 125 grams per square meter linerboard sheets initially at room temperature.



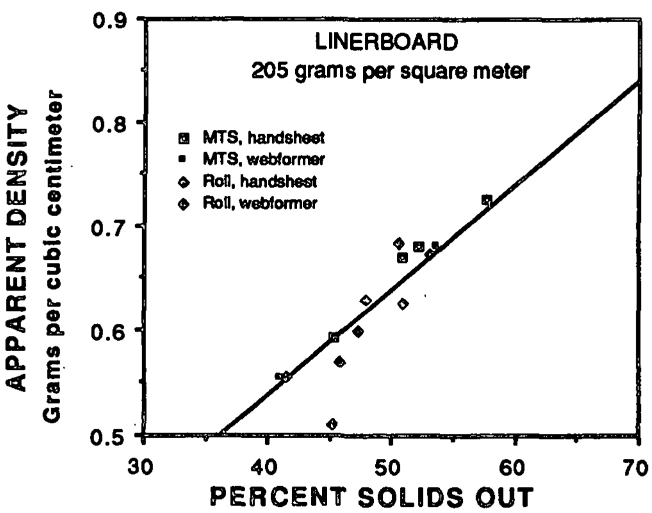


Figure 48. The density - percent solids relationship effects of impulse drying geometry and sheet type. All tests run at 400 psi peak pressure and 500°F for 50 or 100 milliseconds using 205 grams per square meter linerboard sheets initially at room temperature.

The strength achieved by densification also does not depend on impulse drying geometry, as indicated by the tensile strength data for handsheets shown in Figure 49. No systematic variations caused by using a roll impulse dryer rather than the MTS platen press were detected in the final physical properties of the sheets.

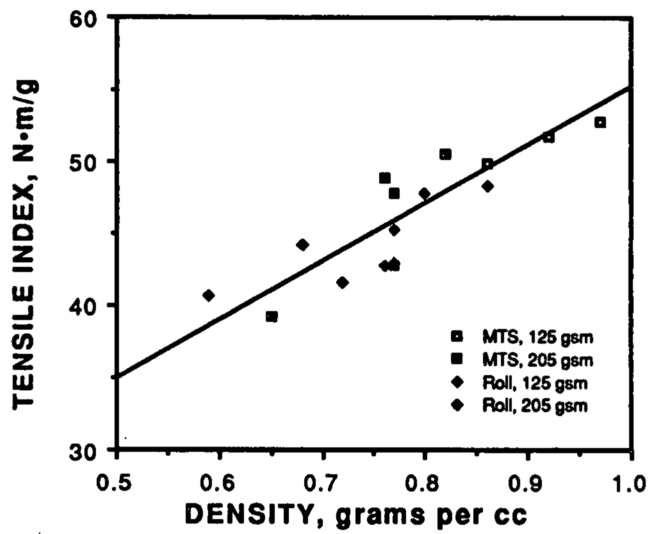


Figure 49. Tensile strength development with densification as developed in the platen press (MTS) and roll impulse dryer configurations. 125 and 205 grams per square meter linerboard handsheets were impulse dried at 500°F and 400 psi for 50 and 100 milliseconds from initial solids of 25 and 50%.

Sheet Surface Quality Issues

The next series of experiments was designed to characterize the surface quality of linerboard, principally through the Bristow test and evaluation of double-backer bonding simulator (DBBS) results. Five-foot-long web former samples of 42-lb linerboard were impulse dried for these experiments. The samples were impulse dried on one side at 500°F, 400 psi and 50 or 100 milliseconds. Relatively long times were used to emphasize any heat-related changes in surface quality.

The double-backer bonding simulator (DBBS) was developed at The Institute of Paper Chemistry to provide a bench-scale predictor of gluing performance on commercial corrugators. A schematic of the DBBS is presented in Figure 50. In the DBBS, glue is applied to a short section of corrugating medium (a commercial medium sample in these tests). The glued flutes are then pressed against a strip of linerboard. The combined medium and liner are then peeled apart, while the force required to break the glue bond at each flute tip is monitored. The test provides three pieces of information. First, the time required to develop any measurable bond strength is recorded. Next, the rate at which bond strength develops over time after the initial induction period is completed is observed. Finally, the time required to develop five pounds per flute of bond strength is noted. Improved conversion performance is indicated by reduced induction time, faster bond strength development, and shorter times to 5 pounds of bond strength.

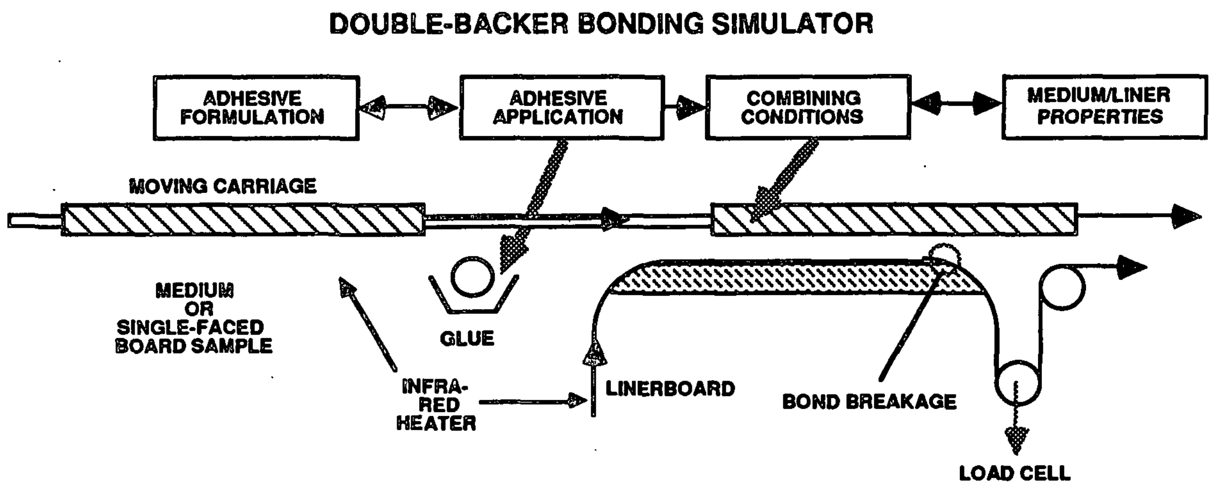


Figure 50. The Institute of Paper Chemistry double-backer bonding simulator (DBBS).

The DBBS results are shown in Figures 51, 52 and 53. The DBBS evaluations were performed on both the side of the board which faced the hot roll during impulse drying and on its unheated side, although gluing on the "cold" side would be more likely to take full advantage of the surface appearance of the impulse dried board. A control sample which was conventionally pressed and dried but not impulse dried was also evaluated for comparison.

The results show that all the DBBS parameters are either unchanged or are improved by impulse drying. Glueability improves on both hot and cold sides of the sheet. Figure 51 shows that the induction time before the glue sets remains constant when the glue joints are made on the hot side of the impulse dried sheet and actually

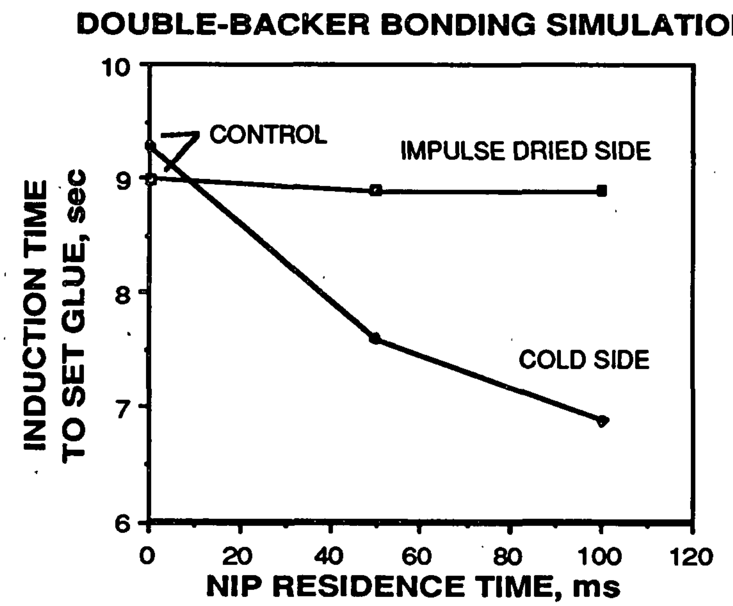


Figure 51. Induction time before glue bond strength develops as a function of impulse drying nip residence time; 400 psi peak pressure and 500°F surface temperature.

improves by about 20% when made on the cold side of the sheet. The rate of development of bond strength is unchanged on the cold side of the sheet (Figure 52). The control board was initially very different on the two sides of the sheet in terms of the rate of bond strength development; improvements on the impulse dried side almost removed the difference. The time needed to develop 5 pounds of glue bond strength, Figure 53, also improved significantly when the sheet was impulse dried. Both sides of the sheet improved, with the cold side giving the best overall performance.

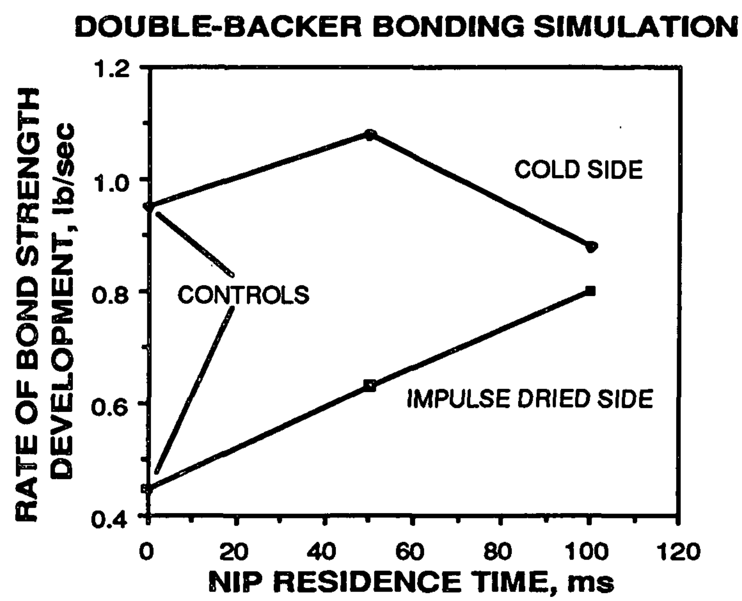


Figure 52. Rate of glue bond strength development as a function of impulse drying nip residence time; 400 psi peak pressure and 500°F surface temperature.

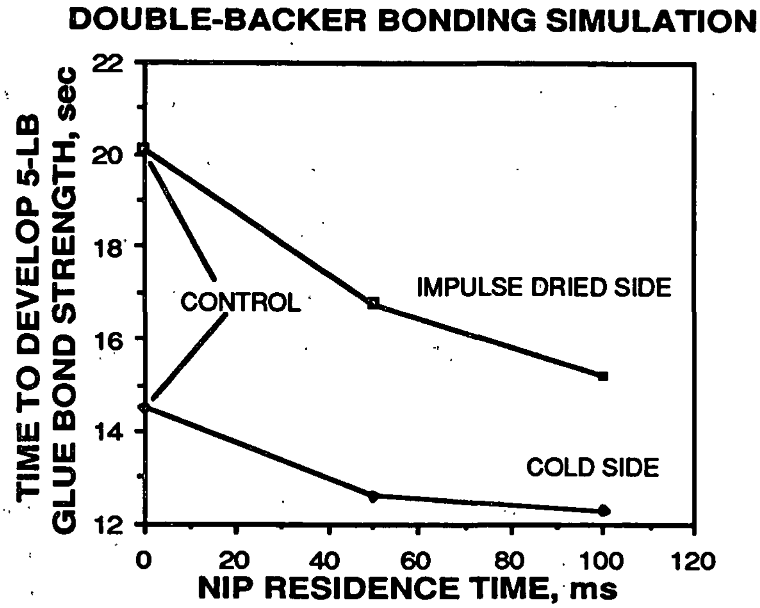


Figure 53. Time to develop 5 lb of glue bond strength as a function of impulse drying nip residence time; 400 psi peak pressure and 500°F surface temperature.

These results are encouraging, as the somewhat water resistant impulse dried surface might have interfered with bond formation. A duplicate run of this experiment has been completed to confirm these important observations. Bristow test results and physical property tests from these experiments are still underway. All of these results are more favorable than similar results for commercial linerboard samples.

PLANS FOR THE COMING YEAR

During the period from October 1987 through October 1988, we expect to expand both the performance attribute evaluation of impulse drying and improve our fundamental understanding of the process. The major single activity will be the construction of a second nip for the pilot roll impulse dryer (Figure 54) which will allow us to

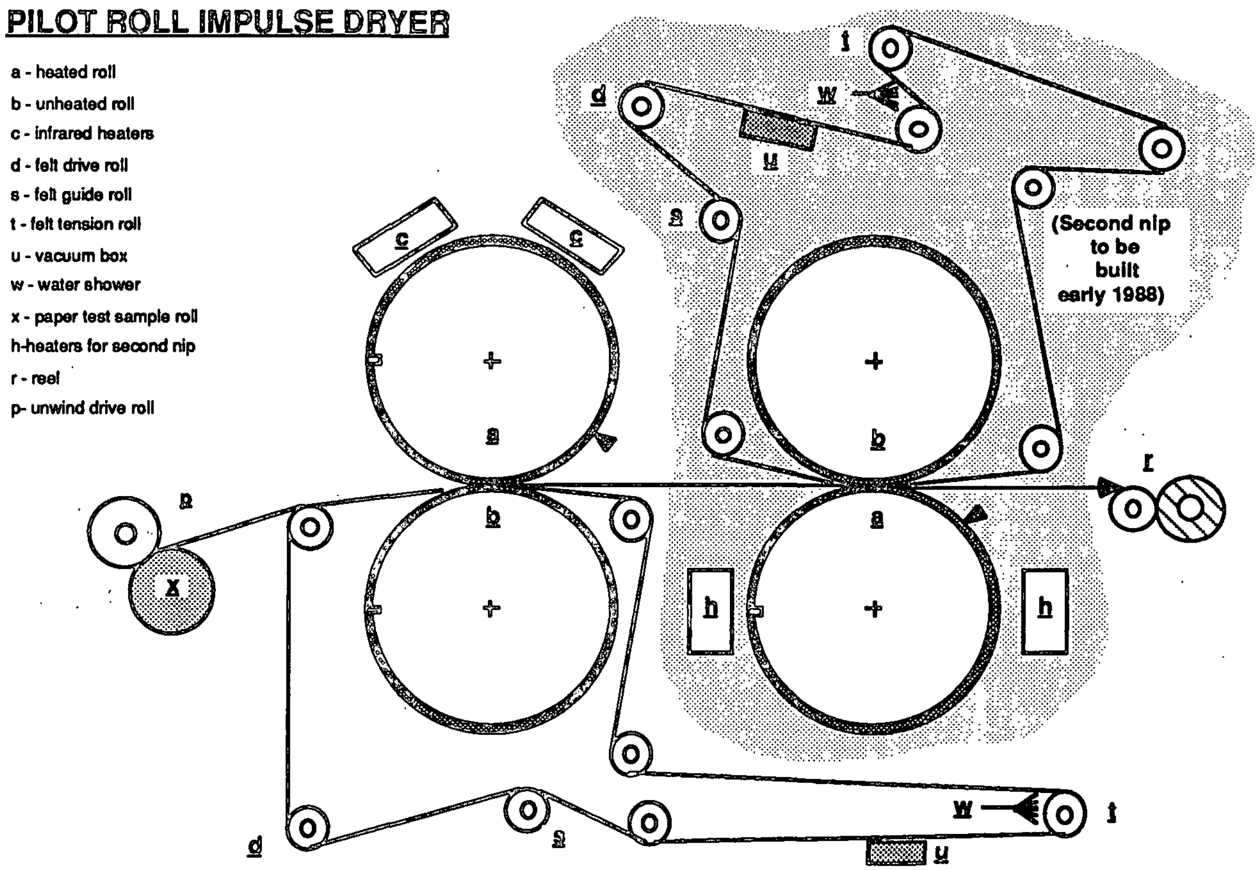


Figure 54. Final design of the pilot roll impulse dryer, showing the configuration of the second nip, which will be built during 1988.

develop methods to produce newsprint and fine paper products while minimizing the differences in sheet surface quality between the two sides of the sheet. We will also complete the single-nip evaluation of the surface quality and conversion performance of impulse dried sheets. Fundamental understanding of the process will be enhanced through Gary Rudemiller's doctoral thesis work, plus additional project work on the effects of temperature and pressure on the heat transfer processes during impulse drying which will be performed as time permits. Further work on the mechanisms of delamination will be pursued both in project research and as part of three Masters' student research projects. A timeline including the major goals for the project is presented in Figure 55.

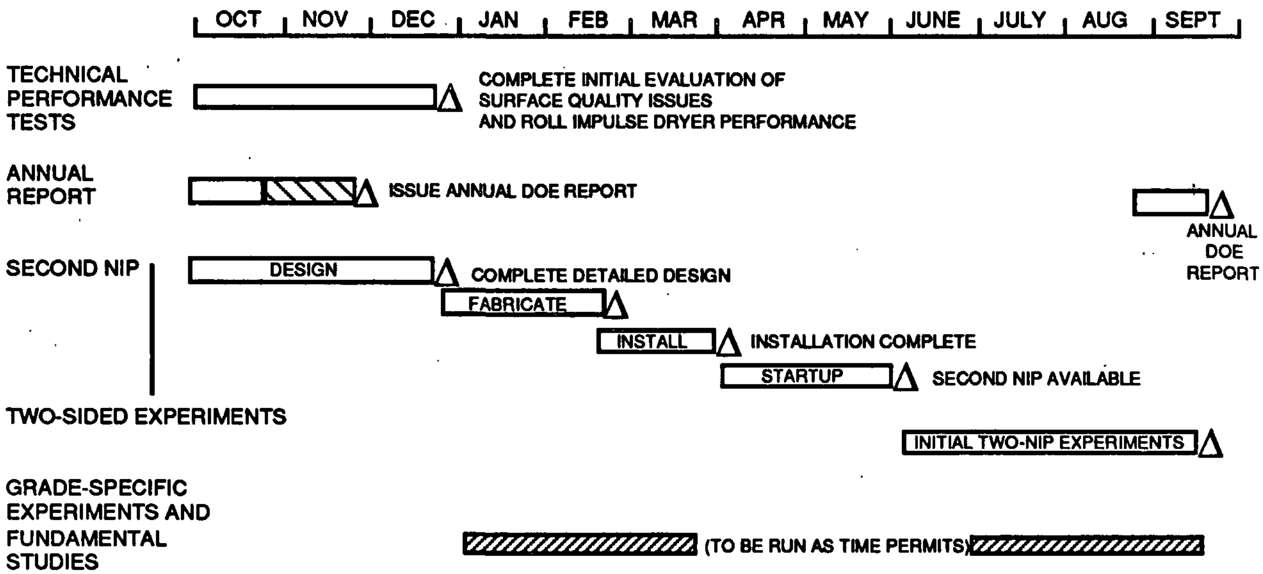


Figure 55. Timeline for project activities during 1988.

COMPLETION OF SHEET SURFACE QUALITY STUDIES

The work remaining on the sheet surface quality issues includes the following grades and issues:

1. Corrugating medium: Physical properties, including CONCORA test, Bristow test of surface water receptivity, and double-backer bonding simulator effects in combination with conventional and impulse dried linerboard,

2. Newsprint: Physical properties, printing performance,

3. Writing papers (freesheet): Physical properties, offset printing performance,

4. Lightweight coating rawstock: pilot scale coating performance, printing evaluations.

Pilot conversion and laboratory evaluation of the product should be essentially complete before April, 1988. Further two-sided sheet quality work on newsprint, writing papers and coating rawstock will be performed during the summer of 1988, after the second nip is completed.

CONSTRUCTION OF SECOND NIP OF THE ROLL IMPULSE DRYER

The construction of a second nip for the pilot impulse dryer is needed to permit rapid evaluation of combinations of nip conditions. A large number of combinations of temperature and pressure are possible in a two-nip system. A choice of variables which minimizes two-sidedness in the final product must be identified for newsprint and fine paper grades.

The second nip will be a duplicate of the first nip, but with the lower roll heated. The design concept is shown in Figure 54. The second nip is essentially a duplicate of the first nip, which was described in detail in a previous report (2). The sole major design change is the use of electrical induction heating on the hot roll of the second nip to provide narrower bands of cross-direction temperature control to evaluate the potential moisture profile control capability of impulse drying. Detailed design is now in progress, with the goal of a final design by the end of December, 1987. Construction will be complete by the end of April, 1988 with the machine available for the initial two-sided experiments by the end of June, 1988. The matrix of conditions to be tested during these experiments will be determined in part after reviewing the results of the one-sided experiments now in progress.

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